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(54) [Title of the Invention]

EXPOSURE APPARATUS, EXPOSURE METHOD, AND DEVICE
MANUFACTURING METHOD

(57) [Abstract]

[Problem]

To realize a high-precision transfer of a fine pattern.

[Means for Resolution]

By an illuminating optical system IL including a light source 1 and a polarization control element 5, a reticle 18 having a pattern formed to include a major line pattern extending in an X direction is irradiated with a slit-shaped illumination light I_4 which has a main component of a linear polarization in a polarization direction parallel to the X direction and which has a longitudinal direction in the X direction. The reticle 18 held on a reticle stage 19 and a wafer 25 held on a wafer stage 26 are moved along a Y direction by the stages 19 and 26 so that a projected image by a projecting optical system 24 of the pattern of the reticle 18 is sequentially transferred to the wafer 25.

[Selected Drawing] Fig. 1

[Claims]

[Claim 1]

A scanning type exposure apparatus for transferring the image of a pattern formed on a mask onto a substrate, characterized: by comprising

a stage device for moving said mask and said substrate relatively along a first direction,

an illuminating optical system for illuminating said mask, and

a projecting optical system for projecting the pattern of said mask on said substrate; and

in that said illuminating optical system illuminates said mask such that the polarization state of the illumination light to irradiate said substrate through said projecting optical system may make a main component of the linear polarization in the polarization direction parallel to a second direction perpendicular to said first direction.

[Claim 2]

An exposure apparatus as set forth in claim 1, characterized in that the illumination light to irradiate said substrate has a degree of polarization of 80 % or more.

[Claim 3]

An exposure apparatus as set forth in claim 1 or 2, characterized in that said illuminating optical system includes a shaping device for shaping the sectional shape of the illumination light to irradiate said substrate, into a slit shape having a longitudinal direction in said second direction.

[Claim 4]

An exposure apparatus as set forth in any of claims 1 to 3,

characterized in that said stage device holds said mask such that the longitudinal direction and said second direction of line patterns of the patterns formed on said mask are substantially parallel.

[Claim 5]

An exposure apparatus as set forth in any of claims 1 to 4, characterized in that said illuminating optical system includes an adjusting device for adjusting the light from a light source, into an illumination light having a main component of a linear polarization in a polarization direction parallel to said second direction.

[Claim 6]

An exposure apparatus as set forth in any of claims 1 to 5, characterized in that said illuminating optical system includes a switching mechanism for switching it selectively whether the illumination light to irradiate said substrate through said projecting optical system is an illumination light having a main component of the linear polarization in the polarization direction parallel to said second direction, or a natural light or a circular polarization or an elliptical polarization.

[Claim 7]

An exposure apparatus for transferring the image of a pattern formed on a mask, under an illumination light, onto a substrate through a projecting optical system, characterized by comprising:

a shaping device for shaping the exposure view field exposure field of said projecting optical system on said substrate, into a shape having a longitudinal direction; and

an adjusting device for adjusting at least one of the polarization direction of said illumination light and said shaping device, to make the longitudinal direction of the exposure view

fieldexposure field on said substrate and the polarization direction of said illumination light parallel to each other.

[Claim 8]

An exposure apparatus as set forth in claim 7, characterized:
by further comprising an illuminating optical system for illuminating said mask with said illumination light; and
in that said shaping device is disposed in said illuminating optical system.

[Claim 9]

An exposure apparatus as set forth in claim 7, characterized in that said adjusting device adjusts the light from the light source, into an illumination light having a main component of the polarization direction parallel to the longitudinal direction of the exposure view fieldexposure field on said substrate.

[Claim 10]

An exposure apparatus as set forth in any of claims 7 to 9, characterized:

by further comprising a stage device for moving said mask and said substrate relatively along a first direction; and

in that the longitudinal direction of said exposure view fieldexposure field is perpendicular to said first direction.

[Claim 11]

An exposure apparatus as set forth in any of claims 1 to 10, characterized:

in that said illuminating optical system includes a plurality of optical elements formed of a fluoride crystal; and

in that said plural optical elements are different in the optical axis direction of said illuminating optical system between the kind

of the crystalline axis of optical elements of one portion and the kind of the crystalline axis of the optical elements of the other portion.

[Claim 12]

An exposure apparatus as set forth in claim 11, characterized in that the crystalline axis of the optical elements of said one portion and perpendicular to the optical axis direction of said illuminating optical system and the crystalline axis of the optical elements of said other portion and perpendicular to the optical axis direction of said illuminating optical system are arranged to rotate relative to each other on the center axis or the optical axis of said illuminating optical system.

[Claim 13]

An exposure method for transferring, while moving a mask having a pattern formed thereon and a substrate relative to each other along a first direction, the pattern of said mask to said substrate through a projecting optical system,

characterized in that an illumination light to irradiate said substrate is an illumination light of a slit shape having a longitudinal direction in a second direction perpendicular to said first direction, and having a main component of a linear polarization parallel to said second direction.

[Claim 14]

An exposure method as set forth in claim 13, characterized in that the exposure is performed such that, of said pattern formed on said mask, a line pattern is set to have its longitudinal direction substantially parallel to said second direction.

[Claim 15]

An exposure method as set forth in claim 13 or 14, characterized in that said illumination light has a degree of polarization of 80 % or more.

[Claim 16]

An exposure method for transferring, under an illumination light, the image of a pattern formed on a mask, onto a substrate through a projecting optical system, characterized by:

shaping the exposure field of viewexposure field of said projecting optical system on said substrate into a shape having a longitudinal direction; and

transferring the image of the pattern of said mask onto said substrate such that the polarization direction of an illumination light to irradiate said substrate is parallel to the longitudinal direction of the exposure view fieldexposure field on said substrate.

[Claim 17]

An exposure method as set forth in claim 16, characterized in that the exposure is performed such that, of said pattern formed on said mask, a line pattern is set to have its longitudinal direction substantially parallel to the longitudinal direction of said exposure view fieldexposure field.

[Claim 18]

An exposure method as set forth in claim 16 or 18, characterized in that, when the exposure is performed with said mask and said substrate being relatively moved along a first direction, the longitudinal direction of said exposure view fieldexposure field is perpendicular to said first direction.

[Claim 19]

A device manufacturing method using an exposure apparatus as

set forth in any of claims 1 to 12, characterized:

in that a silicon crystal substrate, in which a direction normal to its surface is substantially aligned with a [111] crystalline axis, is used as said substrate; and

in that said substrate is exposed to said illumination light such that either a [11-2] crystalline axis perpendicular to said [111] crystalline axis or a crystalline axis equivalent to the former is aligned with said second direction or the longitudinal direction of said exposure view field exposure field.

[Claim 20]

A device manufacturing method as set forth in claim 19, characterized in that said substrate is so exposed to the gate pattern formed on said mask, as to be substantially parallel to either said [11-2] crystalline axis or a crystalline axis equivalent to the former.

[Claim 21]

A device manufacturing method using an exposure apparatus as set forth in any of claims 1 to 12, characterized:

in that a silicon crystal substrate, in which a direction normal to its surface is substantially aligned with a [110] crystalline axis, is used as said substrate; and

in that said substrate is exposed to said illumination light such that either a [00-1] crystalline axis perpendicular to said [110] crystalline axis or a crystalline axis equivalent to the former is aligned with said second direction or the longitudinal direction of said exposure view field exposure field.

[Claim 22]

A device manufacturing method as set forth in claim 21,

characterized in that said substrate is so exposed to the gate pattern formed on said mask, as to be substantially parallel to either said [00-1] crystalline axis or a crystalline axis equivalent to the former.

[Claim 23]

A device manufacturing method using an exposure apparatus as set forth in any of claims 1 to 12, characterized:

in that a semiconductor wafer, in which a semiconductor crystalline structure of its surface layer is distorted at least in one predetermined direction, is used as said substrate; and

in that said substrate is exposed such that the direction for the highest mobility of at least electrons or holes in said surface layer is aligned with either said first direction or a direction perpendicular to the longitudinal direction of said exposure view field exposure field.

[Claim 24]

A device manufacturing method as set forth in claim 23, characterized in that said surface layer is a silicon crystalline layer.

[Claim 25]

A device manufacturing method using an exposure apparatus as set forth in any of claims 13 to 18, characterized:

in that a silicon crystal substrate, in which a direction normal to its surface is substantially aligned with a [111] crystalline axis, is used as said substrate; and

in that said substrate is exposed to said illumination light such that either a [11-2] crystalline axis perpendicular to said [111] crystalline axis or a crystalline axis equivalent to the former is

aligned with said second direction or the longitudinal direction of said exposure view fieldexposure field.

[Claim 26]

A device manufacturing method as set forth in claim 25, characterized in that said substrate is so exposed to the gate pattern formed on said mask, as to be substantially parallel to either said [11-2] crystalline axis or a crystalline axis equivalent to the former.

[Claim 27]

A device manufacturing method using an exposure method as set forth in any of claims 13 to 18, characterized:

in that a silicon crystal substrate, in which a direction normal to its surface is substantially aligned with a [110] crystalline axis, is used as said substrate; and

in that said substrate is exposed to said illumination light such that either a [00-1] crystalline axis perpendicular to said [110] crystalline axis or a crystalline axis equivalent to the former is aligned with said second direction or the longitudinal direction of said exposure view fieldexposure field.

[Claim 28]

A device manufacturing method as set forth in claim 27, characterized in that said substrate is so exposed to the gate pattern formed on said mask, as to be substantially parallel to either said [00-1] crystalline axis or a crystalline axis equivalent to the former.

[Claim 29]

A device manufacturing method using an exposure method as set forth in any of claims 13 to 18, characterized:

in that a semiconductor wafer, in which a semiconductor crystalline structure of its surface layer is distorted at least in one predetermined direction, is used as said substrate; and

in that said substrate is exposed such that the direction for the highest mobility of at least electrons or holes in said surface layer is aligned with either said first direction or a direction perpendicular to the longitudinal direction of said exposure view fieldexposure field.

[Claim 30]

A device manufacturing method as set forth in claim 29, characterized in that said surface layer is a silicon crystalline layer.

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention Belongs]

The present invention relates to an exposure apparatus, an exposure method and a device manufacturing method, which are used when a semiconductor integrated circuit, a liquid crystal display element, a thin film magnetic head, another micro device, or a photomask is manufactured by using a photolithographic technique.

[0002]

[Prior Art]

When a fine pattern of an electronic device such as a semiconductor integrated circuit or a liquid crystal display is to be formed, there is used a method for reducing, exposing and transferring the pattern of a reticle (a mask, as also called so), which is drawn by proportionally enlarging a pattern to be formed by four or five times, to an exposed substrate such as a wafer by using

a projecting exposure apparatus.

[0003]

The projecting exposure apparatus used in the transfer has been shifted in its exposure wavelength to a shorter side so as to match the miniaturization of the semiconductor integrated circuit. At present, 248 nm of a KrF excimer laser is becoming the mainstream, but a shorter wavelength of 193 nm of an ArF excimer laser is coming into the practical stage. There is also proposed a projecting exposure apparatus using a light source of a shorter wavelength band, as called the "vacuum ultraviolet range", such as a F₂ laser having a wavelength of 157 nm or an Ar₂ laser having a wavelength of 126 nm.

[0004]

On the other hand, a high resolution can be made not only by shortening the wavelength but also by enlarging the numeral aperture (NA) of an optical system. Thus, a development has been made to enlarge increase the NA of the optical system more. For realizing the high resolution, it is necessary to reduce the aberration of the projecting optical system. In the process for manufacturing the projecting optical system, therefore, a wavefront aberration measurement using the optical interference is performed to measure the residual aberration in an accuracy of about 1/1000 of the exposure wavelength so that the projecting optical system is adjusted on the basis of the measured value.

[0005]

These large NA and small aberration are easier to realize for the optical system of the smaller field of view. However, the exposure apparatus has the processing ability (or throughput) improved the better for the larger view field (or exposure field). In order to

acquire a substantially large exposure field by using a projecting optical system having a small view field but a large NA, the recent mainstream is the scan type exposure apparatus, in which the mask and the wafer are relatively scanned during the exposure while keeping their focusing imaging relation.

[0006]

The projecting optical system, as used in the scan type exposure apparatus, has a good image rangeimage area (or a good exposure view fieldexposure field) of a rectangular type, which is generally long in one direction and short in a perpendicular direction. This optical system may use a reflection optical systemcataptric optical system but generally uses a refractive optical systemdioptric optical system. In this case, the aforementioned rectangular exposure view fieldexposure field is generally formed from the circular shape or the intrinsic good image rangeimage area, as made of a combination of circular lenses, of the refractive optical systemdioptric optical system, to a rectangular shape, which includes the center of that circle and is inscribed with that circle. This is because that rectangular view field can maximize the length of the longer side of the view field and accordingly the efficiency.

[0007]

In case, however, a cata-dioptriccatadioptric system is adopted as the projecting optical system, the good image rangeimage area of the projecting optical system is not always the circular shape. Therefore, the exposure view fieldexposure field is neither always the rectangular shape including the diameter of the circle, but may be a rectangle having its center eccentric from the center of the circle.

[0008]

The direction for a relative scan is perpendicular to the longer side direction. As a result, the view field of the projecting optical system in the shorter direction of the rectangle is enlarged by that relative scanning so that the narrow view field in the shorter side direction raises no problem.

[0009]

[Problems that the Invention is to Solve]

As described above, the exposure area to be exposed by the scan type exposure apparatus is obtained for one direction by the view field of the projecting optical system, and the focusing performance imaging performance of the projecting optical system also changes according to that position so that the transfer characteristics of the pattern also change.

[0010]

On the other hand, the perpendicular direction is enlarged by the relative scan between the reticle and the wafer, and the focusing performance imaging performance of the projecting optical system is uniform in its direction.

[0011]

Generally in the optical system, there is left the aberration to degrade the focusing characteristic imaging characteristics. In the projecting optical system for the projecting exposure apparatus, the residual aberration is extremely less than that of an optical system for another application. It is, however, unavoidable to leave the aberration of some extent.

[0012]

As these residual aberrations, there are the components (or the

radial components) to blur the transfer image in the radial direction from the optical axis of the projecting optical system to the circumference, and the components (or the concentric components) to blur the transfer image in the concentric direction on the optical axis of the projecting optical system. Of these, the radial components are generally larger.

[0013]

The aberrations of the radial components are coma aberrations and chromatic aberrations of a magnificationmagnification chromatic aberration. The coma aberrations are hard to correct on the design and from the manufacturing error, and are difficult to eliminate completely. The corrections of the chromatic aberrations of the magnificationmagnification chromatic aberration require a large quantity of expensive lens material for correcting the secondary spectrum of the lenses, so that the lens price extremely rises for the complete corrections. On the other hand, the influences of the chromatic aberrations can be reduced by narrowing (for the narrow band) the wavelength width of a light source such as a laser (e.g., an excimer laser). As the laser has the narrower band, however, its output drops so that the exposure light illuminance on the wafer surface drops. As a result, the elongation of the illumination time is needed to lower the processing ability (or the throughput) of the exposure apparatus so that the production yield drops. Because of a lifetime of the optical elements needed for the narrower laser band, the optical elements have to be periodically replaced to raise the running cost for the laser.

[0014]

The present invention has been made to solve those problems,

and has an object to realize an exposure apparatus, an exposure method and a device manufacturing method, which can perform a high-precision transfer of important ones of patterns to be transferred to a substrate, and which can transfer a pattern equivalent to or higher than that of the prior art even if when they use an optical system having the aberrations of concentric components such as the magnification chromatic aberrations or the partial coma aberrations left therein.

[0015]

[Means for Solving the Problems]

In the description to be made under this title, the invention will be described in connection with the reference numerals shown in the drawings explaining the mode of embodiments. However, the individual components of the invention should not be limited to those designated by those reference numerals in the drawings.

[0016]

In order to solve the aforementioned problems, according to a first aspect of the invention, there is provided a scanning type exposure apparatus for transferring the image of a pattern formed on a mask (18) onto a substrate (25) comprising a stage device (19, 26) for moving said mask and said substrate relatively along a first direction (a Y direction), an illuminating optical system (IL) for illuminating said mask, and a projecting optical system (24) for projecting the pattern of said mask on said substrate, wherein said illuminating optical system has a function to illuminate said mask such that the polarization state of the illumination light to irradiate said substrate through said projecting optical system may make a main component of the linear polarization in the polarization direction parallel to a second direction perpendicular to said first

direction. Here, "to make a main component of the linear polarization" means the complete polarization, in which said illumination light is composed of only said linear polarization, or the partial polarization including the natural light or another polarization. It is desired that said illumination light has a degree of polarization of 80 % or more, in case it is a partial polarization. The "degree of polarization" is the ratio of the energy of said linear polarization of said partial polarization to the whole energy. Moreover, the "polarization direction" is the direction of the electric- field vector of a light.

[0017]

According to the invention, when the pattern of the mask is to be transferred to the substrate, the polarization state of the illumination light (or the exposure light) to irradiate the substrate is made to have the main component of the linear polarization of the polarization direction parallel to the second direction perpendicular to the first direction as the moving direction, and the pattern of the mask is exposed and transferred to the substrate. Of the pattern formed on the mask, the contrast of the projected image on the line pattern extending in the direction along said second direction can be raised to transfer the fine pattern highly precisely.

[0018]

In the invention, said illuminating optical system (IL) includes a shaping device (14) for shaping the sectional shape of the illumination light to irradiate said substrate, into a slit shape (a rectangular shape, a strip shape) having a longitudinal direction in said second direction. As a result, the adverse influences due to the residual aberration of the projecting optical system can be

alleviated relaxed to make the transfer more precise. Here, said mask and said substrate are in the focusing relation (in which the pattern of the mask is projected). Therefore, the sectional shape of the illumination light on said substrate can be made into the slit shape by forming the sectional shape of the illumination light (I_4) to irradiate said mask (18) into the slit shape.

[0019]

In these cases, said stage device (19, 26) holds said mask such that the longitudinal direction and said second direction (or an X direction) of line patterns (32 to 34) of the patterns formed on said mask (18) are substantially parallel. In case said line patterns are two or more kinds in mutually different directions (e.g., mutually perpendicular directions), said mask is desirably held such that, of said line patterns, a major line pattern to perform the highly precise transfer has a longitudinal direction substantially parallel to said second direction. Since the exposure precision on the line pattern extending in the direction along the second direction can be raised, as described above, the exposure precision of said main line patterns can be enhanced by setting the main line pattern positively along said second direction.

[0020]

In the invention, said illuminating optical system (IL) can include an adjusting device (5) for illuminating said substrate (25) with the light (I_0) fed from a light source (1), as an illumination light having a main component of a linear polarization in a polarization direction parallel to said second direction (or an X direction) through said projecting optical system (24). In case the light source (1) for feeding supplying the light to the illuminating

optical system (IL) emits the light having a main component of the linear polarization in the polarization direction parallel to a specific direction, said adjusting device (5) is exemplified by a polarization rotating device (e.g., a $1/2$ wavelength plate wave-plate), in which the polarization direction of said linear polarization of the illumination light to irradiate said substrate (25) rotates the polarization plane along said second direction. However, that adjusting device (5) need not be used, but the optical system position relation between said light source (1) and said illuminating optical system (IL) may be so suitably set that the illumination light having the main component of the linear polarization in the polarization direction parallel to said second direction is guided to irradiate said substrate through said projecting optical system. In case, on the other hand, the light source (1) to feed the light to the illuminating optical system (IL) emits a natural light or another polarization light (e.g., a circle polarization or an elliptic polarization), said adjusting device (5) is exemplified by a linear polarization device (e.g., a linear polarization element polarizer or a $1/4$ wavelength plate wave-plate) for adjusting the light from said light source into an illumination light having a main component of the linear polarization of the polarization direction parallel to said second direction.

[0021]

In the invention, said illuminating optical system (IL) can include a switching mechanism for switching it selectively whether the illumination light to irradiate said substrate (25) through said projecting optical system (24) is an illumination light having a main component of the linear polarization in the polarization direction

parallel to said second direction, or a natural light or a circular polarization or an elliptical polarization. As a result, the proper illumination light can be selected according to the contents of the pattern to be exposed and transferred.

[0022]

In order to solve the aforementioned problems, according to a second aspect of the invention, there is provided an exposure apparatus for transferring the image of a pattern formed on a mask (18), under an illumination light (I_4), onto a substrate (25) through a projecting optical system (24) comprising: a shaping device (14) for shaping the exposure view field of said projecting optical system (24) on said substrate, into a shape having a longitudinal direction; and an adjusting device (5) for adjusting at least one of the polarization direction of said illumination light (I_4) and said shaping device (14), to make the longitudinal direction of the exposure view field of said projecting optical system on said substrate and the polarization direction of said illumination light to irradiate said substrate parallel to each other.

[0023]

The exposure apparatus of the invention can comprise an illuminating optical system (IL) for illuminating said mask with said illumination light (I_4), and said shaping device (14) can be disposed in said illuminating optical system (IL).

[0024]

In the invention, moreover, said adjusting device (5) can adjust the light from the light source, into an illumination light having a main component of the linear polarization direction parallel to the longitudinal direction of the exposure view field of

said projecting optical system on said substrate.

[0025]

Moreover, the exposure apparatus of the invention can comprise a stage device (19, 26) for moving said mask (18) and said substrate (25) relatively along a first direction (or a Y direction), and the longitudinal direction of said exposure view field exposure field can be the direction (or an X direction) perpendicular to said first direction.

[0026]

According to a third aspect of the invention, in an exposure apparatus according to the first or second aspect of the invention, said illuminating optical system includes a plurality of optical elements formed of a fluoride crystal, and said plural optical elements are different in the optical axis direction of said illuminating optical system between the kind of the crystalline axis of optical elements of one portion and the kind of the crystalline axis of the optical elements of the other portion.

[0027]

In this case, the crystalline axis of the optical elements of said one portion and perpendicular to the optical axis direction of said illuminating optical system and the crystalline axis of the optical elements of said other portion and perpendicular to the optical axis direction of said illuminating optical system can be arranged to rotate relative to each other on the center axis or the optical axis of said illuminating optical system.

[0028]

Here, the phrase "the kind of the crystalline axis of optical elements of one portion and the kind of the crystalline axis of the

optical elements of the other portion are different" means that, in case the crystalline axis of the illuminating optical system axial direction of said optical elements of one portion is the [111] crystalline axis, for example, the crystalline axis of the illuminating optical system axial direction of said optical elements of the other portion is the crystalline axis (e.g., the [100] crystalline axis) other than the [111] crystalline axis.

[0029]

By arranging the plural optical elements in the predetermined relation, as described above, the birefringence owned by said optical elements can be corrected or offset to reduce the adverse influences to the polarization direction or the polarization state of the illumination light by said birefringence.

[0030]

In order to solve the aforementioned problems, according to a fourth aspect of the invention, there is provided an exposure method for transferring, while moving a mask (18) having a pattern formed thereon and a substrate (25) relative to each other along a first direction (or a Y direction), the pattern of said mask to said substrate through a projecting optical system, wherein an illumination light to irradiate said substrate is an illumination light of a slit shape having a longitudinal direction in a second direction perpendicular to said first direction, and having a main component of a linear polarization parallel to said second direction. In this case, of said pattern formed on said mask, a line pattern is desirably set to have its longitudinal direction substantially parallel to said second direction.

[0031]

Here, the "illumination light having a main component of a linear polarization" means either the complete polarization, in which said illumination light has only said linear polarization as a component, or a natural light or a partial polarization containing another polarization. It is desired that said illumination light has a degree of polarization of 80 % or more in the case of the partial polarization. The "degree of polarization" is the ratio of the energy of said linear polarization of said partial polarization to the whole energy. Moreover, the "polarization direction" is the direction of the electric-field vector of a light.

[0032]

According to the invention, the linear polarization of the polarization direction parallel to the second direction perpendicular to the first direction as the moving direction is used as the main component, and the exposure is made by using the slit-shaped illumination light having the longitudinal direction in said second direction. Of the pattern formed on the mask, the contrast of the projected image on the line pattern extending in the direction along said second direction can be raised, and the adverse influences due to the aberration of the projecting optical system for projecting the pattern of the mask on the substrate can be alleviatedrelaxed to transfer the fine pattern highly precisely.

[0033]

In order to solve the aforementioned problems, according to a fifth aspect of the invention, there is provided an exposure method for transferring, under an illumination light (I_4), the image of a pattern formed on a mask (18), onto a substrate (25) through a projecting optical system (24). The exposure method is characterized

by shaping the exposure field of view exposure field of said projecting optical system (24) into a shape having a longitudinal direction, and by transferring the image of the pattern of said mask onto said substrate such that the polarization direction of an illumination light (I_4) is parallel to the longitudinal direction of said exposure view field exposure field.

[0034]

In the invention, the exposure can be performed such that, of said pattern formed on said mask, a line pattern is set to have its longitudinal direction substantially parallel to the longitudinal direction of said exposure view field exposure field.

[0035]

In the invention, moreover, when the exposure is performed with said mask (18) and said substrate (25) being relatively moved along a first direction (or a Y direction), the longitudinal direction of said exposure view field exposure field is perpendicular to said first direction.

[0036]

According to a sixth aspect of the invention, in the exposure apparatus according to the first, second or third aspect of the invention or in the exposure method according to the fourth or fifth aspect of the invention, there is provided a device manufacturing method using an exposure apparatus characterized in that a silicon crystal substrate, in which a direction normal to its surface is substantially aligned with a [111] crystalline axis, is used as said substrate, and

in that said substrate is exposed to said illumination light such that either a [11-2] crystalline axis perpendicular to said [111]

crystalline axis or a crystalline axis equivalent to the former is aligned with said second direction or the longitudinal direction of said exposure view fieldexposure field. In this case, said substrate can be so exposed to the gate pattern formed on said mask, as to be substantially parallel to either said [11-2] crystalline axis or a crystalline axis equivalent to the former. Thus, it is possible to manufacture a semiconductor device capable of acting at a higher speed, and another electronic device.

[0037]

According to a seventh aspect of the invention, in the exposure apparatus according to the first, second or third aspect of the invention or in the exposure method according to the fourth or fifth aspect of the invention, there is provided a device manufacturing method using an exposure apparatus characterized in that a silicon crystal substrate, in which a direction normal to its surface is substantially aligned with a [110] crystalline axis, is used as said substrate, and in that said substrate is exposed to said illumination light such that either a [00-1] crystalline axis perpendicular to said [110] crystalline axis or a crystalline axis equivalent to the former is aligned with said second direction or the longitudinal direction of said exposure view fieldexposure field. In this case, said substrate can be so exposed to the gate pattern formed on said mask, as to be substantially parallel to either said [00-1] crystalline axis or a crystalline axis equivalent to the former. Thus, it is possible to manufacture a semiconductor device capable of acting at a higher speed, and another electronic device.

[0038]

According to an eighth aspect of the invention, in the exposure

apparatus according to the first, second or third aspect of the invention or in the exposure method according to the fourth or fifth aspect of the invention, there is provided a device manufacturing method using an exposure apparatus, characterized in that a semiconductor wafer, in which a semiconductor crystalline structure of its surface layer is distorted at least in one predetermined direction, is used as said substrate, and in that said substrate is exposed such that the direction for the highest mobility of at least electrons or holes in said surface layer is aligned with either said first direction or a direction perpendicular to the longitudinal direction of said exposure view field exposure field. In this case, said surface layer can be exemplified by a semiconductor wafer owned by a silicon crystalline layer. Thus, it is possible to manufacture a semiconductor device capable of acting at a higher speed, and another electronic device.

[0039]

In Specification of this patent application, the phrase of "the crystalline axis and the equivalent crystalline axis" means a crystalline axis having the order of indexes of a crystalline axis interchanged, and a crystalline axis having signs of at least a portion of their individual indexes partially inverted. In case a crystalline axis is [abc], the following crystalline axes are equivalent:

[acb], [bac], [bca], [cab], [cba], [-abc], [-acb], [-bac], [-bca], [-cab], [-cba], [a-bc], [a-cb], [b-ac], [b-ca], [c-ab], [c-ba], [ab-c], [ac-b], [ba-c], [bc-a], [ca-b], [cb-a], [a-bc], [-a-cb], [-b-ac], [-b-ca], [-c-ab], [-c-ba], [a-b-c], [a-c-b], [b-a-c], [b-c-a], [c-a-b], [c-b-a], [-a-b-c], [-a-c-b], [-b-a-c], [-b-c-a], [-c-a-b], and [-c-b-a].

[0040]

[Mode of Embodiment of the Invention]

Modes of embodiment of the invention are described in the following with reference to the accompanying drawings.

[0041]

Fig. 1 is a diagram showing a schematic constitution of an exposure apparatus according to a mode of embodiment of the invention. This exposure apparatus is a step-and-scan type (or scanning type) projecting exposure apparatus. Here in the following description, an XYZ orthogonal coordinate system shown in Fig. 1 is set, and description is made with reference to the XYZ orthogonal coordinate system. In the XYZ orthogonal coordinate system, the Y-axis and the Z-axis are set parallel to the sheet face, and the X-axis is set normal to the sheet face. In the shown XYZ coordinate system, the XY plane is set parallel to the horizontal plane, and the Z-axis is set upward of the vertical line. The direction along the Y-axis is the scan (or scanning) direction.

[0042]

A scan type projecting exposure apparatus according to this mode of embodiment is constituted to include a light source 1, an illuminating optical system 1L, a projecting optical system 24 and a stage device having a reticle stage 19 and a wafer stage 26.

[0043]

A reticle (or mask) 18 having a pattern to be transferred is sucked and held on the reticle stage 19 placed on a reticle stoolreticle surface plate 22, so that it can be scanned in the Y direction as shown over the reticle stoolreticle surface plate 22 by the reticle stage 19. A reticle side moving mirror 20 is disposed over the reticle stage

19, and a reticle side laser interferometer 21 is arranged to confront the reticle side moving mirror 20. The measured value by the reticle side laser interferometer 21 is fed to the not-shown stage control device so that the actions of the reticle stage 19 are controlled by that stage control device.

[0044]

The reticle 18 sucked and held by the reticle stage 19 is irradiated with an illumination light I_1 by the illuminating optical system 1L. The reticle stoolreticle surface plate 22 has an aperture 23 for passing the illumination light I_1 so that the illumination light (or a diffracted light) having passed through the reticle 18 enters the projecting optical system 24 through the aperture 23. By the focusing action of the projecting optical system 24, moreover, the projected image of the pattern on the reticle 18 is formed on a semiconductor wafer (or a sensitive substrate) 25 as the exposed substrate. This projected image photosensitizes the photoresist applied to the surface of the wafer 25 so that the reticle pattern is transferred to the surface of the wafer 25.

[0045]

The wafer 25 is sucked and held by the wafer stage 26 placed on a wafer stoolwafer surface plate 29 so that it can be scanned in the Y direction, as shown, over the wafer stoolwafer surface plate 29 by the wafer stage 26. Over the wafer stage 26, there is disposed a wafer side moving mirror 27, which is confronted by a wafer side laser interferometer 28. The measured value by the wafer side laser interferometer 28 is fed to the stage control device, by which the wafer stage 26 is controlled to move synchronously with the movement of the reticle stage 19. Here, the wafer stage 26 is enabled not only

to scan in the Y direction but also to perform stepping movements in the X direction and in the Y direction. In order to transfer the projected images of the reticle pattern to a plurality of shot areas set all over the surface of the wafer 25, the scanning exposures in the Y direction are repeated while the wafer 25 being sequentially stepwise moved in the XY directions.

[0046]

An illumination light I_0 , as emitted from the light source 1 such as a KrF (krypton-fluorine) excimer laser (having a wavelength of 248 nm), an ArF (argon-fluorine) excimer laser (having a wavelength of 193 nm) or a F_2 (a fluorine molecule) laser (having a wavelength of 157 nm), is fed to the illuminating optical system IL.

[0047]

The illuminating optical system IL has a constitution, as follows. The illumination light I_0 fed from the light source 1 is guided a polarizing mirror 2 and shaping optical systems 3 and 4 so that it enters a polarization control element (or an adjusting device) 5. The detail of this polarization control element 5 will be described hereinafter.

[0048]

An illumination light I_1 having passed through the polarization control element 5 enters a first illumination uniforming member 6 such as a fly-eyefly' s eye lens or a diffraction grating. The luminous fluxlight beam having emanated the first illumination uniforming member 6 passes through relay lenses 7 and 8, and enters a second illumination uniforming member 9 such as a fly-eyefly' s eye lens. The illumination uniforming member 9 is equipped on its emanating side face with an illumination aperture stop (or a σ diaphragm) 10. This

illumination aperture stop 10 can be exemplified by a circular stop (or an iris stop) having a variable radius, an ring-shapedannular-shaped stop or a modified illumination stop having a plurality of apertures. These stops are arranged on a rotatable revolver so that they can be selectively arranged by rotating and positioning the revolver properly.

[0049]

The luminous fluxlight beam having emanated the illumination aperture stop 10 arrives, through a relay lens 11, a bending mirrorfolding mirror 12 and a relay lens 13, at a field stop 14. The field stop 14 (or a shaping device) is a device or member for restricting the illuminated field of view on the reticle 18.

[0050]

The present exposure apparatus is the scan type exposure apparatus, and the reticle 18 and the wafer 25 are scanned for the exposure in the Y direction. Therefore, the illumination field of viewillumination field on the reticle 18 is such a slit shape (or a rectangular shape) as is long in the X direction and short in the Y direction. Considering the reflection characteristics of a bending mirrorfolding mirror 17, therefore, the field stop 14 is formed into such a rectangular shape as is long in the X direction and short in the Z direction. In order to adjust the width of the slit, it is further preferred that the stops defining the two ends of the field stop 14 in the Z direction can move in the Z direction. Like discussion applies to the X direction. The luminous fluxlight beam having passed through the field stop 14 irradiates the reticle 18 through relay lenses 15 and 16 and the bending mirrorfolding mirror 17.

[0051]

The polarization control element 5 is an optical element for controlling the polarization state of the illumination light I_0 to a predetermined state. In this predetermined state, the illumination light to irradiate the reticle 18 is a generally linear polarization, and its polarization direction (i.e., the direction of the electric-optical field vector of light) is aligned in the X direction, as shown. In the apparatus shown in Fig. 1, the polarization direction at the emanating position of the polarization control element 5 is also set in the X direction.

[0052]

The ordinary projecting optical system does not contain such a member (e.g., a wavelength plate wave-plate or a polarization beam splitter) as changes the polarization direction of the illumination light (or the exposure light). Therefore, if when the polarization state of the illumination light to irradiate the reticle 18, as described above, is made parallel (or coincident with) to the X direction shown in the figure (i.e., the longitudinal direction of the field of view of the projecting optical system), the polarization state of the illumination light (or the exposure light) to irradiate the wafer through the mask and the projecting optical system is also generally parallel to the longitudinal direction of the field of view of the projecting optical system. Thus, the following description is made, premising that the polarization state of the illumination light to irradiate the reticle and the polarization state of the illumination light (or the focused light) to irradiate the wafer are equivalent.

[0053]

The emanation light (or the illumination light I_0) of the

aforementioned excimer laser light source or the fluorine laser light source is a generally linear polarization light. In order to align the polarization direction of that linear polarization with the aforementioned predetermined direction, the $1/2$ wavelength platewave-plate, which is made of an optical material such as quartz crystal (crystal of silicon dioxide) or magnesium fluoride crystal having a birefringence is inserted in the predetermined direction. Here, that polarization control element 5 need not be provided in the optically relative positional relation between the light source 1 and the illuminating optical system IL, in case the polarization direction of the illumination light I_c to be fed from the light source 1 to the illuminating optical system IL is aligned from the beginning with the aforementioned predetermined direction (or the X direction).

[0054]

In case the light source 1 emits a luminous fluxlight beam other than the linear polarization as in the lamp or the random polarization laser, the polarization filter or the polarization beam splitter for transmitting only the linear polarization in the aforementioned predetermined direction is used as the polarization control element 5.

[0055]

Here, the illumination light for irradiating the reticle 18 need not be a complete linear polarization, but the invention can exhibit its effect if the illumination light intensity is almost (e.g., about 80 % or more) a predetermined linear polarization. In case, therefore, the aforementioned polarization filter or polarization beam splitter is used, its polarization selection ratio is sufficient if it is at or over about 80 %. In case a fluorine laser with no narrowed band

is used as the light source, the illumination light I_0 is a linear polarization of some extent, and contains a linear polarization perpendicular to the former. For the similar reasoning, the illumination light need not be linearly polarized any more.

[0056]

Fig. 2 is a top plan view showing one example of the reticle, which is being placed on the reticle stage 19. As shown in Fig. 2, patterns 32, 33 and 34 are drawn as major line patterns in a pattern area 30 of the reticle 18. These patterns 32, 33 and 34 are thin in line widths for transistor gates and strict in the width uniformity required, and require high-precision transfers so that they are formed along a predetermined direction. In the pattern area 30, there are formed other patterns (although not shown), which have relatively large widths such as wiring patterns formed at the end portions of the transistor gates, which are loose in the line width uniformity and which are formed along directions different from that of the patterns 32, 33 and 34.

[0057]

In this mode of embodiment, as shown in Fig. 2, the reticle 18 is so adsorbed and held on the reticle stage 19 that its major patterns 32, 33 and 34 extend generally in parallel with the X direction. Of the patterns to be transferred, specifically, the patterns 32, 33 and 34, which have the fine line width and important line width uniformity, are set in the X direction.

[0058]

In Fig. 2, an area 31, as shown by broken lines in the pattern area 30, corresponds to the exposure field of view exposure field of the projecting optical system 24, and is so inscribed in a good image

rangeimage area 40 of the projecting optical system 24 that its center is aligned with the optical axis AX of the projecting optical system 24. However, the exposure field of viewexposure field of the projecting optical system 24 may be set eccentric with respect to the good image rangeimage area 40 of the projecting optical system 24. In this case, the center of the exposure field of viewexposure field is not aligned with the optical axis AX of the projecting optical system 24. The illumination light I_4 , with which the reticle 18 is irradiated by the illuminating optical system IL, irradiates that area. The polarization state of the illumination light I_4 has a major component of a linear polarization having a polarization direction in the X direction, as indicated by E in Fig. 2.

[0059]

At the exposure, the reticle 18 and the wafer 25 are scanned in the Y direction relative to each other while keeping their focusing relation. Therefore, the pattern (i.e., the pattern 34 and so on) not in the exposure field of viewexposure field 31, as shown in Fig. 2, is sequentially brought by that scan into the exposure field of viewexposure field 31 so that it is transferred to the wafer 25.

[0060]

Here is described one of the feature of the invention, that is, the relation between the pattern direction and the longer direction of the exposure field of viewexposure field or the polarization direction of the illumination light.

[0061]

Figs. 3(A) to 3(C) and Figs. 4(A) to 4(D) are diagrams for showing the relations between the pattern direction and the polarization direction. Fig. 3(A) and Fig. 4(A) show the case, in which a pattern

36 extending in the X direction is irradiated with a linear polarization I_{41} having the polarization direction E_1 aligned with the X direction and a linear polarization I_{42} having the polarization direction E_2 aligned with the Y direction.

[0062]

The illumination lights I_{41} and I_{42} , as diffracted by the pattern 36 extending in the Y direction, generate diffracted lights, respectively, in the +Y direction and the -Y direction. These diffracted lights are shown as a 0-th diffracted light D01, a -1st diffracted light DM1 and a +1st diffracted light DP1 in Fig. 3(A), and are shown as a 0-th diffracted light D02, a -1st diffracted light DM2 and a +1st diffracted light DP2 in Fig. 4(A). In the polarization state of each diffracted light, the polarization state of each illumination light I_{41} or I_{42} is stored. On an eye plane pupil plane EP of the projecting optical system 24, the diffracted lights D01, DM1 and DP1 in Fig. 3(A) are linear polarizations in the X direction, and the diffracted lights D02, DM2 and DP2 in Fig. 4(A) are linear polarizations in the Y direction.

[0063]

The advancing directions of these diffracted lights (i.e., the diffracted lights diverged in the Y direction from the pattern (i.e., the pattern in the X direction) extending in the X direction, as described above) are diffracted again in the Y directions, after having passed through the eye plane pupil plane EP, by the focusing action of the projecting optical system 24, and are condensed again on the wafer 25 so that interference fringes or the images of the pattern 36 are formed. The wafer 25 is irradiated (or illuminated) with those interference fringes so that the image is recorded on the

photoresist applied to the wafer surface.

[0064]

In addition to the refractions of the luminous fluxlight beam, the polarization direction is rotated in a direction perpendicular to the advancing direction of the luminous fluxlight beam. This rotation follows the physical law of the light, in which the direction of the electric field is always perpendicular to the advancing direction of the light.

[0065]

The diffracted lights DM2 and DP2 in Fig. 4(A) are linear polarizations in the Y direction on the eye planepupil plane EP, but their polarization direction change with the refractions of the diffracted lights DM2 and DP2. Fig. 4(B) is an enlarged diagram near the wafer 25 of Fig. 4(A). The polarization directions of the diffracted lights DM2 and DP2 are normal to the advancing directions of the individual luminous fluxlight esbeams and are offset from the Y direction. However, the advancing direction of the diffracted light D02 is the -Z direction so that the polarization direction is kept in the Y direction.

[0066]

The intensity distribution of the interference fringes (images) by such luminous fluxlight esbeams is the sum (the sum of X components is 0) of the square (or the energy) (the intensity distribution IM2 indicated by a solid line in Fig. 4(C)) of the sum of the Y direction components of the individual polarizations (or the electric field) and the square (or the energy) (the intensity distribution IM3 indicated by a broken line in Fig. 4(C)) of the sum of the Z direction components of the individual polarizations (or the electric field),

and becomes the intensity distribution IM4 of Fig. 4 (D). At this time, however, the Z direction components of the electric fields of the diffracted lights DM2 and DP2 are inverted in their signs by the relations of the two polarization angles. As a result, the intensity distribution IM3 is offset in phase from the intensity distribution of the image formed by the Y direction component of the electric field thereby to lower the image contrast.

[0067]

As shown in Fig. 4 (A), therefore, the pattern in the X direction is illuminated with the linear polarization of the Y direction. Then, the polarization directions of the illumination lights (or the individual diffracted lights) to irradiate the wafer are not parallel to each other. As a result, the contrast of the projected image drops so that it is not suitable for the transfer of a fine pattern.

[0068]

On the contrary, the polarization direction of the luminous fluxlight beam in the X direction on the eye plane pupil plane EP, like the diffracted lights D01, DM1 and DP1 in Fig. 3(A), is kept in the X direction even if the advancing direction of the luminous fluxlight beam is refracted in the Y direction. As shown in Fig. 3 (B), moreover, the wafer 25 is irradiated by the diffracted lights D01, DM1 and DP1 having their polarization directions arranged in the X direction, so that the interference fringes are formed. This interference fringe intensity distribution is determined from the square of the sum of the X direction components of the electric field (because the sum of the Y and Z components is 0), as shown as an intensity distribution IM1 in Fig. 3(C). This means that the contrast is high because the components have no inverted sign unlike the case of Fig. 4 (A).

[0069]

The pattern of the X direction is so illuminated by the linear polarization having the polarization direction in the X direction that all the polarization directions of the illumination lights (or the individual diffracted lights) to irradiate the wafer may be parallel to the X direction, as shown in Fig. 3(A). Then, the projected image has such a high contrast as suits for the transfer of a fine pattern.

[0070]

Next, the relations between the pattern direction and the longer side direction of the exposure field of view exposure field are described with reference to Fig. 5. Fig. 5 shows the exposure view field exposure field 31 of the projecting optical system 24. The exposure view field exposure field 31 is formed into a rectangular shape having a longer side along the X direction and a shorter side along the Y direction. Moreover, the exposure view field exposure field 31 frequently has its center C aligned with the optical axis AX of the projecting optical system 24, as has been described hereinbefore.

[0071]

The point image intensity distribution or the focusing characteristic imaging characteristics on a point 39 close to the end of the X direction on the exposure view field exposure field 31 are extended broadened (or blurred) in the radial direction and the concentric circle direction (i.e., in the X direction and in the Y direction for the point 39 in Fig. 5) of the projecting optical system 24 by the influences of the principle diffraction limits and the residual aberrations of the projecting optical system 24. As shown, point image intensity distributions 60 and 61 designate the X

direction section (or the radial direction section) and the Y direction section (or the concentric direction section) of the point image intensity distribution at the position of the point 39, respectively. Thus, it is general that the extending width of the point image distribution is made larger in the radial direction than in the concentric direction by the influences of the residual aberrations. The residual aberrations are various ones, of which the coma aberration and the magnification chromatic aberration are the major causes for making the extension of the point image distribution larger in the radial direction than that in the concentric direction.

[0072]

Of these aberrations, the coma aberration is difficult to remove completely, not only in the design but also in the manufacturing error. On the other hand, the magnification chromatic aberration can be eliminated by means of countermeasures, e.g., by using a suitable material (e.g., fluorite) for eliminating the chromatic aberration in a large quantity as the material of lenses constituting the projecting optical system 24, or by making the projecting optical system 24 into a cata-diopticcatadioptic system having concave mirrors assembled therein. However, either the countermeasure is followed by the problem of raising the cost for manufacturing the projecting optical system.

[0073]

Because of those aberrations left in the projecting optical system, in the periphery of the exposure view fieldexposure field 31, a pattern 37 parallel to the longer side of the exposure view fieldexposure field 31 is less subjected to the influences of the residual aberrations than a pattern 38 perpendicular to the longer

side direction of the exposure view field exposure field 31, so that the finer pattern can be transferred.

[0074]

In this mode of embodiment, of the patterns to be transferred, the pattern having a fine line width and a very important line width uniformity is directed in the X direction (i.e., the direction of the pattern 37), so that its transfer image is hardly subjected to the influences of the aforementioned aberration in the radial direction. Even if the same projecting optical system as that of the prior art is used, it is possible to resolve the finer pattern. Moreover, the illumination light to be emitted from the illuminating optical system IL is the linear polarization in the X direction or the most proper illumination for the pattern in the aforementioned X direction (i.e., the direction parallel to the longer side direction of the exposure view field exposure field 31), so that a finer pattern than that of the prior art can be resolved.

[0075]

If When the pattern to be exposed may be as fine as that of the prior art, the allowance of the residual aberration in the radial direction of the projecting optical system 24 used can be made looser than that of the projecting optical system of the prior art. Especially by relaxing the magnification aberration allowance, the cost for the projecting optical system can be lowered to provide an inexpensive projecting exposure apparatus.

[0076]

While leaving the chromatic aberration correction of the projecting optical system 24 as it is, moreover, the spectral width of the light source 1 can be loosened. In the case of the narrowed

laser, the loosening of the spectral width means the simplification of the laser band narrowing element, and can augment the laser output and elongate the lifetime of band-narrowed element, can improve the operating ability of the exposure apparatus, and can reduce the running cost for the band-narrowed element and for the exposure apparatus.

[0077]

Here in the aforementioned mode of embodiment, the reticle 18 is irradiated with the illumination light I_4 having a main component in the polarization direction parallel to the X direction. Depending upon the pattern to be exposed, the polarization state of the illumination light to irradiate the reticle 18 may be preferably an unpolarization (or a natural light), a circular polarization or an elliptical polarization. In this mode of embodiment, therefore, the polarization control element 5 is desirably made removable or rotatable on the axis of the advancing direction of the illumination light.

[0078]

For example, the light source 1 is a laser light source for emitting a luminous fluxlight beam of a generally linear polarization, and a $1/2$ wavelength platewave-plate is used as the polarization control element 5. In this case, as shown in Fig. 6, the polarization control element 5 is composed of two $1/4$ wavelength platewave-plates 51 and 52. By the individual rotations on the axis of the advancing direction of the illumination light I_0 , the luminous fluxlight beam I_1 to be emitted can be made into a linear polarization or a circular polarization.

[0079]

Specifically, in case the exit light I_1 is a linear polarization, it is sufficient to arrange the mutual longer axis direction of the $1/4$ wavelength platewave-plates 51 and 52, and to set the direction of the exit light I_1 intermediate between the polarization direction of the incident light I_0 and the desired polarization direction of the exit light I_1 . In order to make the exit light I_1 into a circular polarization, it is sufficient to align the longer axis direction of the $1/4$ wavelength platewave-plate 51 on the light source side with the polarization direction of the incident light I_0 and to rotate the longer axis direction of the other $1/4$ wavelength platewave-plate 52 by 45 degrees with respect to the aforementioned polarization direction.

[0080]

In case the light source 1 emits the an unpolarized light, moreover, the polarization state of the illumination light I_4 to irradiate the reticle 18 can be made variable by mounting and demounting a polarization filter or a polarization beam splitter as the polarization control element 5.

[0081]

Here, this mode of embodiment has been described on the step-and-scan type exposure apparatus, in which the pattern of the mask is transferred to the substrate while the mask and the substrate moving relative to each other, and in which the substrate is moved sequentially stepwise. However, the exposure may also be performed by the step-and-repeat type, in which the exposure view field exposure field having the longer side direction and the shorter side direction is used to transfer the pattern of the mask to the substrate while the mask and the substrate being stationary, and in which the substrate

is moved sequentially stepwise. This step-and-repeat type exposure apparatus is different from the step-and-scan type exposure apparatus in that the exposure is performed with the mask and the substrate being stationary from each other, and the remaining constitution can be identical to that of the step-and-scan type exposure apparatus. In case the invention is applied to the step-and-repeat type exposure apparatus, the polarization direction of the illumination light for the pattern of the mask is adjusted by the polarization control element 5, the field stop 14 is rotated on the optical axis of the illuminating optical system so that the longer side direction of the exposure field of the projecting optical system and the polarization direction of the illumination light can be parallel to each other. In case the polarization direction of the illumination light to be fed from the light source is identical from the beginning to a predetermined direction, it is sufficient to rotate the field stop 14 without providing the polarization control element.

[0082]

Here, in case the light source of the exposure apparatus is a vacuum ultraviolet ray such as the F_2 laser, the material for the transmission optical member of the used lens is exemplified by the so-called "modified quartz" such as fluoride crystal such as fluorite or fluorine added quartz having a high transmission to the vacuum ultraviolet ray. Moreover, the optical path has to be replaced, when used, by a rare or nitrogen gas having a high transmission to the vacuum ultraviolet ray.

[0083]

Here in the exposure apparatus using the F_2 laser as the light source, the material, which can be used as a lens to be adopted in

the illuminating optical system or the projecting optical system, is substantially limited to the fluorite by the transmittance. The fluorite is a crystal belonging to a cubic system, and has been thought in the prior art to cause no birefringence intrinsic to the crystal. In the 157 nm Symposium held (at Dana Point of California, USA) by International SEMTECH (Semiconductor Manufacturing Technology Institute), in May, 2001, it was published by NIST (National Institute of Standards and Technology) that the fluorite had the birefringence intrinsic to the crystal in the vacuum ultraviolet range.

[0084]

In the exposure apparatus using the random polarization illumination of the prior art, the birefringence of the lens material making the illuminating optical system has little influence on the final focusing performance imaging performance. In the prior art, therefore, no problem has been raised by the intrinsic birefringence of the fluorite lens arranged in the illuminating optical system.

[0085]

In case the mask pattern is illuminated with a linear polarization as in the invention, the rotation of the polarization direction accompanying the intrinsic birefringence of the fluorite lens in the illuminating optical system may raise a problem. Specifically, the intrinsic birefringence of the fluorite lens may act as the $1/2$ wavelength plate wave-plate or the $1/4$ wavelength plate wave-plate thereby to deviate the polarization direction of the illumination light to illuminate the mask pattern face, from a desired direction. In accordance with the place in the mask pattern plane, moreover, the polarization state of the illumination light may be different. Therefore, the following countermeasures are desired in

the exposure apparatus using the F_2 laser as the illuminating light source and adopting the crystal material such as the fluorite in the illuminating optical system.

[0086]

The following countermeasures are desired. Specifically, of fluorite lenses (of an S number) arranged in the illuminating optical system, a predetermined number (A) of fluorite lenses are arranged to have their optical axes aligned with the crystalline axis $[111]$, and a predetermined number (a) of lenses, and the remaining number ($A - a$) of lenses are arranged to have their optical axes on the rotation center and to have their crystalline axes rotated by 60 degrees from each other. The remaining number $B (= S - A)$ of lenses are arranged to have their optical axes aligned with the crystalline axis $[100]$, and a predetermined number (b) lenses, and the remaining number ($B - b$) of lenses are arranged to have their optical axes on the rotation center and to have their crystalline axes rotated by 45 degrees from each other.

[0087]

Fig. 7 exemplifies the case, in which the aforementioned countermeasures are applied to the four lenses in the illuminating optical system. All four lenses $L1$, $L2$, $L3$ and $L4$, as arrayed along the optical axis LAX of the illuminating optical system, are made of fluorite. Of these, the lenses $L1$ and $L2$ have their optical axes (aligned with the optical axis LAX of the illuminating optical system) aligned with the $[100]$ axis of the fluorite crystal, and the crystalline axes (i.e., the $[010]$ axis and the $[001]$ axis) of the fluorite crystal in the in-plane direction of the two lenses (i.e., in the plane normal to the optical axis LAX) are rotated by 45 degrees,

as shown.

[0088]

On the other hand, the lenses L3 and L4 have their optical axes (aligned with the optical axis LAX of the illuminating optical system) aligned with the [111] axis of the fluorite crystal, and the crystalline axes (i.e., the [0-11] axis, the [-110] axis and the [-101] axis) of the fluorite crystal in the in-plane direction of the two lenses (i.e., in the plane normal to the optical axis LAX) are rotated by 60 degrees, as shown.

[0089]

By applying those countermeasures to the illuminating optical system, the polarization state of the illumination light on the mask pattern plane can be made into the desired linear polarization, so that the effects of the invention can be sufficiently exhibited.

[0090]

In case the fluorite is adopted for the lenses in the projecting optical system, the influences for the intrinsic birefringence to give the focusing performance imaging performance of the projecting optical system can be solved by optimizing what crystalline axis the optical axes of each fluorite lens used is aligned with, or what angle each lens is rotated and arranged by on the optical axis, as reported by our report SPIE (International Society for Optical Engineering Microlithography Symposium) in March, 2002.

[0091]

Here, the foregoing mode of embodiment has been described with the premise that the projecting optical system contains none of the member (e.g., the wavelength plate wave-plate or the polarization beam splitter) for changing the polarization direction of the illumination

light (or the exposure light). In a kind of cata-dioptriccatadioptric system, however, there is contained a polarization state changing member such as a wavelength platewave-plate or a polarization beam splitter. In this case, the exposure view fieldexposure field of the projecting optical system frequently has a slit shape. However, the polarization state of the illumination light to irradiate the reticle and the polarization state of the illumination light (or the exposure light) to irradiate the wafer side may be changed by the aforementioned polarization state changing member, and their relations between the longitudinal direction and the polarization direction of the exposure view fieldexposure field may not coincide.

[0092]

In case the invention is applied to the exposure apparatus having such projecting optical system, the polarization state of the illumination light to irradiate the reticle is desirably set such that the polarization state of the illumination light (or the exposure light) to irradiate the wafer plane finally through the projecting optical system may be parallel to the longitudinal direction of the exposure view fieldexposure field slit in the wafer plane. Even if when the illumination light on the reticle side is set parallel to the longitudinal direction of the exposure view fieldexposure field slit on the reticle side, the polarization state of the illumination light (or the exposure light) to enter the wafer comes into the undesired state so that the effect of the invention cannot be acquired, when the polarization state by the projecting optical system is changed by the aforementioned polarization state changing member.

[0093]

In the foregoing mode of embodiment, the gas (e.g., the air or

the gas having little absorption to the ultraviolet ray) exists in the space between the projecting optical system and the wafer. However, the invention should not be limited to that existence but may be modified such that the space between the projecting optical system and the wafer is filled with a liquid. This structure is the liquid-immersed optical systemliquid immersion optical system, in which the wavelength of the illumination light (or the exposure light) to irradiate the wafer is reduced by a submultiple of the refractive index of that liquid, thereby to realize a higher improvement of the resolution of the exposure apparatus.

[0094]

In the liquid immersed optical systemliquid immersion optical system, the sinusoidal value of the angle made between the 0-th light and the 1st light of the illumination light (or the exposure light) in the liquid at the time of exposing the pattern of the common pitch in the common wavelength is reduced by a submultiple of the refractive index of that liquid, as compared with the case of the optical system of not the liquid immersed immersion type. In other words, the reduction means that even the projecting optical system of a similar constitution can enlarge increase its numerical aperture by the refractive index of the liquid, and this is a main cause for improving the resolution.

[0095]

In the photoresist for forming a latent image of the pattern actually, however, the refractive index of the photoresist is identical even for the liquid-immersed optical systemliquid immersion optical system and for the ordinary optical system of not the liquid immersed type. Therefore, the sinusoidal value of the angle made

between the 0-th light and the 1st light of the illumination light (or the exposure light) at the time of exposing the pattern of the common pitch in the common wavelength is identical for the two optical systems. In the liquid immersed optical system, liquid immersion optical system to be exposed to a finer (fine pitch) pattern than that of the ordinary optical system, therefore, the deviations in the polarization direction between the diffracted lights (or the exposure lights) of the individual orders in the resist are so large that the image contrast is more lowered, if when the polarization state of the illumination light (or the exposure light) to irradiate the resist is undesirable. By applying the invention to the liquid immersed projecting optical system, therefore, a higher effect can be obtained than that of the case, in which the invention is applied to the projecting optical system of not the liquid immersed type of the prior art.

[0096]

Next, in the C-MOS-LSI or the present mainstream of the semiconductor integrated circuit, an electronic device is generally formed on the surface of a silicon crystal, the <100> plane of which extends in the wafer surface. In the C-MOS-LSI, the n-MOS transistor and the p-MOS transistor form a transistor pair on the surface of the silicon wafer. If the wafer used has the surface of the <100> plane of the crystal, as described above, there arises a problem that the mobility of the holes (or positive holes) of the p-MOS transistor is low.

[0097]

In the silicon wafer having its surface extending in the <111> plane of the crystal (or the wafer having the [111] crystalline axis

normal to the surface), on the other hand, the mobilities of electrons and holes in the axial azimuth $[110]$ in the $\langle 111 \rangle$ plane and in the equivalent azimuth in the $\langle 111 \rangle$ plane are so high that the C-MOS-LSI can act at higher speeds. Here, the equivalent azimuth includes the azimuth, in which the orders of the individual indexes are interchanged, and the azimuth, in which at least one index sign is inverted. Of these, the azimuths existing in the aforementioned $\langle 111 \rangle$ plane are the $[-110]$ axial azimuth, the $[10-1]$ axial azimuth, the $[-101]$ axial azimuth, the $[01-1]$ axial azimuth and the $[0-11]$ axial azimuth.

[0098]

Here, either the $[1-10]$ axis or an equivalent axis has three azimuths individually intersecting at an angle of 120 degrees in the $\langle 111 \rangle$ plane of the crystal. Therefore, if the longitudinal direction of the gate pattern is formed in parallel with the direction in the $\langle 111 \rangle$ plane normal to that azimuth, i.e., the $[11-2]$ crystalline axis or the axial equivalent to the former and existing in the $\langle 111 \rangle$ plane (e.g., the crystalline axis $[1-21]$ and the crystalline axis $[2-1-1]$ crystalline axis), the moving direction of the electrons and holes in the MOS transistor containing that gate can be aligned with the $[1-10]$ axial azimuth or the $[-110]$ axial azimuth of a higher mobility, thereby to acquire a higher speed of the actions of the C-MOS-LSI.

[0099]

As a matter of fact, for a reticle of a square contour, the drawing precision of the fine pattern not in parallel with the side (i.e., the uniformity of the pattern width) is inferior to the parallel fine pattern. It is, therefore, preferred that the pattern azimuths on the reticle are arranged in the direction of the sides of the square

of the reticle contour. If, however, either the $[1-10]$ axis of three azimuths individually intersecting at an angle of 120 degrees or one equivalent axis is aligned with one of the reticle contour in the aforementioned $\langle 111 \rangle$ plane of the crystal, the remaining two azimuths are undesirable ones for the precision in the formation of the reticle pattern. In case, therefore, a higher speed C-MOS-LSI is realized by using the wafer having the $[111]$ axis as the crystalline axis normal to the surface, it is necessary that the longitudinal directions of the substantially usable gate patterns be arranged in one direction (i.e., the $[-112]$ axis and any of the equivalent axial directions). This necessity is examined in the following.

$[0100]$

Fig. 8 (A) is a diagram showing the azimuth of the silicon crystal in the wafer surface of the silicon wafer, in which the crystalline axis normal to the surface is the $[111]$ axis. In short, the wafer surface is included in the $\langle 111 \rangle$ plane of the silicon crystal. As shown, the $[111]$ axis is normal to the sheet face (i.e., normal to the wafer surface). In the wafer plane, the crystalline axes (i.e., the $[0-11]$ axis, the $[-110]$ axis and the $[-101]$ axis), which are equivalent to the $[110]$ axis of the azimuth having the high electron and hole mobilities, are arranged at an angular interval of 120 degrees. In Fig. 8 (A), the rotating direction of the wafer is set in such a predetermined direction as to align the $[-110]$ axis and the shown Y-axis with each other.

$[0101]$

In order to accelerate the action speed of the MOS transistor, it is desired that the moving direction of the electrons and holes in the transistor is aligned with either the aforementioned $[110]$ axis

or an equivalent axial direction. It is, therefore, desired that the longitudinal direction of the gate pattern is oriented to intersect the $[110]$ axis or an equivalent axial direction at a right angle, as indicated by gate patterns G1, G2 and G3 in Fig. 8(A). In the case of Fig. 8(A), therefore, the gate patterns are preferably arranged in the three directions having the relatively rotational relations of 120 degrees of the gate G1, in which the $[11-2]$ axial direction (aligned with the X-axis of the drawing) perpendicular to the $[-110]$ axial direction in the $\langle 111 \rangle$ plane is longitudinal, the gate G2, in which the $[1-21]$ axial direction perpendicular to the $[-101]$ axial direction in the $\langle 111 \rangle$ plane is longitudinal, and the gate G3, in which the $[2-1-1]$ axial direction perpendicular to the $[0-11]$ axial direction in the $\langle 111 \rangle$ plane is longitudinal.

[0102]

Here in Fig. 8(A), a rectangular area EXF, as enclosed by broken lines, is the exposure view field exposure field area of the projecting optical system of the exposure apparatus of this embodiment, and its longer side direction is aligned with the X direction, i.e., the longitudinal direction of the gate G1 and the $[11-2]$ axial direction of the silicon crystal.

[0103]

Fig. 8(B) is a top plan view of the reticle to be used in the exposure apparatus of the embodiment. In a pattern area PA, a master of a pattern to be transferred is drawn. This drawing precision (or the line width precision and the drawing position precision) is so set by the precision of the EB (electron beam) drawing machine for drawing the pattern that the precision is high, in case the pattern is parallel (i.e., in the X direction and in the Y direction) to the

outer side of the reticle (or square), but low in case the pattern is inclined.

[0104]

In order to form the highly precise pattern on the wafer, therefore, it is preferred that the longitudinal direction of the pattern on the reticle is set in the X direction and the Y direction parallel to the outer sides of the reticle, as indicated by patterns P1 and P2. At present, the patterns of such directions are generally used.

[0105]

In case the wafer having the surface of the $\langle 111 \rangle$ plane is used, as shown in Fig. 8(A), the preferred gate pattern direction is limited to the three directions of every 120 degrees. Therefore, the longitudinal directions of the gate patterns, which satisfy both the restriction of the drawing precision of the reticle pattern and the restriction from the transistor action speed, are restricted to only the direction of the gate pattern G1 parallel to the X direction in Fig. 8(A).

[0106]

When the semiconductor device and another electronic device are manufactured by using the projecting exposure apparatus according to the mode of embodiment thus far described, an electronic device capable of acting at a higher speed can be manufactured by arranging the pattern directivity, which is given a high resolution by the projecting exposure apparatus of the mode of embodiment, and the direction of the pattern which is determined from the viewpoints of the transistor action speed and the reticle drawing precision.

[0107]

Specifically, the silicon wafer having its surface included in the $\langle 111 \rangle$ plane of the crystal (that is, having its surface normal to the $[111]$ axis) is used. The silicon wafer is so placed on the wafer stage (26) of the projecting exposure apparatus that its $[-110]$ axis may be aligned with the shorter side direction of the exposure view field exposure field of the projecting optical system (that is, its $[11-2]$ axis may be aligned with the longer side direction of the exposure view field exposure field of the projecting optical system). The silicon wafer is so arranged that the longitudinal direction of the fine gate pattern on the reticle is aligned with the longer side direction of the exposure view field exposure field of the projecting optical system, and is irradiated with the generally linear polarization of the polarization direction (or the electric field direction), in which the polarization direction of the focusing luminous flux light beam leading to the wafer may be substantially aligned with the longer side direction of the exposure view field exposure field of the projecting optical system.

[0108]

As a result, the gate directed suitably for the high-speed actions on the silicon crystal can be exposed and transferred more precisely with a finer line width thereby to improve the performance of the electronic device drastically.

[0109]

For the index of the crystalline axis in the foregoing description, the azimuth vertically normal to the wafer surface is set to the $[111]$ axial direction, on which the indexes of other axes are determined. The substance is not changed in the least, even if the azimuths of other axes are expressed by using that axis as the

axis equivalent to the $[111]$ axis (i.e., the axis having the index of the rearranged order and the axis having the index partially inverted) such as the $[11-1]$ axis or the $[1-11]$ axis. Therefore, even the $[0-11]$ axis, the $[-110]$ axis and the $[-101]$ axis of the silicon wafer surface, as shown in Fig. 8(A), may be other axes, if they are equivalent to the $[110]$ axis. Moreover, it is needless to say that the axis to be aligned with the longer side direction of the exposure view field exposure field of the projecting optical system may be any crystalline axis, so long as it is perpendicular to the axis equivalent to the $[110]$ axis existing in the plane equivalent to the $\langle 111 \rangle$ plane that is, equivalent to the $[112]$ axis.

$[0110]$

In the scanning type exposure apparatus of this embodiment, the projecting optical system has its exposure view field exposure field substantially aligned in its longer side direction with the polarization direction of the illumination light. As a result, the exposure apparatus is excellent in resolution and contrast for the pattern having the longitudinal direction in the direction parallel to the longer side direction of the exposure view field exposure field. Therefore, the exposure apparatus is especially suited for forming the gate pattern arrayed in one direction, on the silicon wafer, in which the crystalline axis normal to the surface is the $[111]$ axis. In addition, the crystalline azimuth of the silicon wafer, in which the crystalline axis normal to the surface is the $[111]$ axis, is so set that the exposure view field exposure field longer side direction and one of the $[11-2]$ axis and the axial azimuth in the equivalent $\langle 111 \rangle$ plane may be parallel. As a result, the preferable condition can be satisfied to manufacture the electronic device capable of

acting at the high speed.

[0111]

Here, the alignment between the longer side direction of the exposure view field exposure field and the predetermined crystalline axis of the wafer is to form the notch, the orientation flat, the identification mark or the like in a predetermined direction of the wafer peripheral edge. This alignment can be easily made by a method similar to the pre-alignment made by the ordinary exposure apparatus.

[0112]

Moreover, the crystalline axis of the wafer need not be made such that the direction normal to the surface and the [111] axis are completely aligned, but the effects of the invention can be sufficiently exhibited if the angular alignment is within about 5 degrees.

[0113]

When a wafer (as will also be called the "[110] wafer", in which a crystalline axis normal to the surface is the [110] axis, is used, the action speed of the transistor on the wafer can be better improved than the case, in which the wafer (as will also be called the "[100] wafer) used in the conventional C-MOS-LSI and having the crystalline axis [100] axis normal to the surface is used, or in which the wafer (as will also be called the "[111] wafer) having the crystalline axis [111] axis normal to the surface is used.

[0114]

In this case, however, the action speed can be improved only in case the moving direction of the electrons or holes in the transistor is generally aligned, as shown in Fig. 9(A), with the axial direction equivalent to the [-110] axis of the surface of the wafer, in which

the crystalline axis normal to the surface is the $[110]$ axis, (that is, the wafer having the surface as the $\langle 110 \rangle$ plane of the crystal).
[0115]

Therefore, the longitudinal direction of the transistor gate pattern to be formed on the wafer should be limited in the X direction in Fig. 9(A), according to a shown pattern G4. In the crystalline axis directions in the wafer shown in Fig. 9(A), the $[-110]$ axis or its equivalent axial direction is aligned with the Y direction, as shown, and the $[00-1]$ axis or its equivalent axial direction is aligned with the X direction, as shown. Moreover, the X direction is aligned with the longer side direction of the view field EXF of the projecting optical system of the exposure apparatus of this mode of embodiment, and with the polarization direction of the main component of the polarization (or the linear polarization) of the illumination light of the exposure apparatus of the mode of embodiment.

[0116]

Thus, with respect to the exposure apparatus of this mode of embodiment, the $[110]$ wafer is arranged in the aforementioned rotational direction (i.e., the rotational direction, in which the $[001]$ axis of the silicon crystal or the equivalent axis is parallel to the polarization direction of the main component of the polarization (or the linear polarization) of the illumination light). As a result, it is possible to transfer more finely and highly precisely the gate pattern of the transistor, in which the moving direction of the electrons and holes is equivalent to either the direction $[-110]$ of the large electron and hole mobilities on the $[110]$ wafer or the equivalent direction (that is, the transistor, in which the longitudinal direction of the gate pattern perpendicular to the moving

direction of the electrons and holes is parallel to the [001] of the silicon crystal or the equivalent axis).

[0117]

As a result, it is possible to manufacture the electronic device (C-MOS-LSI) of a higher speed than that of the prior art.

[0118]

Fig. 9(B) is a top plan view of the reticle to be used in this case. The master of a pattern to be transferred is drawn in the pattern area PA. In case the wafer having the surface of the $\langle 110 \rangle$ plane is used, as shown in Fig. 9(A), the preferred gate direction is limited to one direction so that the longitudinal direction of the pattern master is also limited to the direction of the gate pattern G4 parallel to the X direction in Fig. 9(A).

[0119]

Here, the semiconductor wafer (or the silicon wafer) may also be the distorted silicon, which is recently proposed. The distorted silicon is the wafer surface portion, in which the C-MOS-LSI is formed, and its semiconductor crystalline structure has an intentional distortion (or an extension/shrinkage).

[0120]

On the surface of a silicon wafer, for example, a silicon-germanium crystal having a larger lattice constant than that of a silicon crystal is formed as a thin film, and a silicon crystal is formed again as a thin film on the former thin film. In this case, the uppermost (or surface) silicon layer is tensed by the influence of the lattice constant of the silicon-germanium crystal of the lower layer so that its crystal lattice is extended/shrunk and distorted. As a result, the mobilities of the electrons and holes in the uppermost

(or surface) silicon layer can be raised to improve the action speed of the transistor.

[0121]

Generally speaking, that distortion occurs generally isotropically in the wafer plane, but can also be limited to one predetermined direction by a predetermined process. If the aforementioned silicon-germanium film and the upper silicon film are formed on the [110] plane of the silicon wafer, for example, the distortion direction is also limited substantially to one direction.

[0122]

Thus, in the wafer having its surface distortion limited to one predetermined direction, the electron or hole mobilities in the surface become the maximum in the predetermined one direction or in the perpendicular direction. By aligning the transistor forming direction with the direction to maximize the electron or hole mobilities in that transistor, therefore, the action speed of the transistor can be drastically improved.

[0123]

In this case, it is desired that the longitudinal direction of the gate pattern of the transistor is perpendicular to the direction, in which the electron or hole mobilities take the maximum, and that the longitudinal directions of the gate patterns of all the transistors on the silicon wafer are arranged into one direction.

[0124]

In the exposure apparatus of this mode of embodiment, the wafer is exposed to the illumination light containing much linear polarization parallel to the longer side direction of the rectangular exposure view field exposure field of the projecting optical system.

At the time of exposing the aforementioned anisotropic distorted silicon wafer, therefore, the gate pattern of the transistor is set parallel to the longer side direction (or the second direction) of the exposure view field exposure field of the projecting optical system, so that the highly precise and fine gate pattern having a better line width controllability than that of the exposure apparatus and the exposure method of the prior art can be transferred. Specifically, that direction of the aforementioned anisotropically distorted silicon wafer, in which the mobility of at least either the electrons or the holes takes the maximum, and the polarization direction (or the direction of the electric field) of the illumination light of the generally linear polarization fed by the exposure apparatus, are made perpendicular to each other for the exposure. As a result, the line width of the gate pattern in the electronic device to be manufactured and the uniformity of the line width can be improved better than the prior art so that an electronic device of a higher speed than that of the prior art can be manufactured additionally by adopting the distorted silicon wafer.

[0125]

The foregoing mode of embodiment has been described assuming the C-MOS-LSI as the electronic device. However, the invention should not be limited to that C-MOS-LSI but can be naturally adapted for the manufacture of the n-MOS, the p-MOS or another device.

[0126]

On the other hand, the exposure apparatus should not be limited to the application for manufacturing the semiconductor device but can be widely applied to a liquid crystal exposure apparatus for exposing and transferring the liquid crystal display element pattern to a

rectangular glass plate, or an exposure apparatus for manufacturing a thin film magnetic head. Another application is made to an exposure apparatus for manufacturing a micro machine, a DNA chip or a mask.

[0127]

The exposure apparatus of this mode of embodiment can be manufactured: by assembling an illuminating optical system and a projecting optical system composed of plural lenses and so on, into the exposure apparatus body, and assembling them optically; by mounting a reticle stage and a wafer stage composed of numerous mechanical parts, on the exposure apparatus body, and wiring and piping them; and by performing the overall adjustments (e.g., the electric adjustments and the action confirmations). Here, it is desired that the exposure apparatus is manufactured in a clean room having the temperature and the cleanness controlled.

[0128]

The semiconductor device is manufactured through: the step of performing the function-performance designs of the device generally; the step of creating a reticle based on the designing step; the step of creating a wafer from a silicon material; the step of exposing and transferring the pattern of the reticle to the wafer having a resist applied thereto, by an exposure apparatus, and developing the pattern; the device assembling step (including the dicing step, the bonding step and the packaging step); and the testing step.

[0129]

Here, it is needless to say that the invention should not be limited to the mode of embodiment thus far described but could be modified in various manners within the scope of the invention.

[0130]

[Advantage of the Invention]

According to the invention, as has been described hereinbefore, a substrate is exposed to an illumination light (or exposure light) incident on the substrate, while being irradiated with the illumination light which is mainly composed of a linear polarization in the polarization direction parallel to the direction perpendicular to the moving direction of the mask and the substrate. As a result, the contrast of the projected image on the line pattern extending in the direction along the direction perpendicular to that moving direction can be raised to transfer the fine pattern highly precisely.

[0131]

If When the pattern to be exposed and transferred may be as fine as that of the prior art, the allowance of the residual aberration in the radiation direction of the projecting optical system can be loosened more than that of the projecting optical system of the prior art. By relaxing the magnification aberration allowance, the cost for the projecting optical system can be lowered to provide a less expensive projecting exposure apparatus according to the invention.

[0132]

Moreover, the spectrum width of the light source can also be relaxed while leaving the chromatic aberration correction of the projecting optical system. In the case of the band-narrowed laser, the relaxation of the spectrum width means the simplification of the band-narrowed laser element thereby to raise the laser output, elongate the lifetime of the band-narrowed element and improve the throughput of the exposure apparatus. As a result, it is possible to reduce the running cost of the band-narrowed element and accordingly the running cost of the exposure apparatus.

[0133]

Moreover, the exposure is performed by using the illumination light which is mainly composed of the linear polarization of the polarization direction parallel to the direction normal to the moving direction of the mask and the substrate, and the direction of the pattern such as the gate pattern to be exposed and transferred onto the substrate is optimized in relation to the crystalline axis of the substrate, so that the device manufactured can act at the high speed.

[Brief Description of the Drawings]

[Fig. 1] A diagram showing a schematic constitution of an exposure apparatus according to a mode of embodiment of the invention.

[Fig. 2] A top plan view showing a reticle of a mode of embodiment of the invention.

[Fig. 3] Diagrams showing the relations between the pattern direction and the polarization direction of the mode of embodiment of the invention, and showing the case, in which the pattern direction and the polarization direction are parallel to each other.

[Fig. 4] Diagrams showing the relations between the pattern direction and the polarization direction of the mode of embodiment of the invention, and showing the case, in which the pattern direction and the polarization direction are perpendicular to each other.

[Fig. 5] A diagram showing an exposure field of view exposure field of the mode of embodiment of the invention.

[Fig. 6] A diagram showing one example of the constitution of a polarization control element of the mode of embodiment of the invention.

[Fig. 7] A diagram showing a preferred lens arrangement of the case, in which fluorite lenses are used in an illuminating optical system

of the mode of embodiment of the invention.

[Fig. 8] Diagrams showing the relations between a wafer crystal axis and a pattern forming direction of a mode of embodiment of the invention, (A) a top plan view of a wafer, and (B) a top plan view of a reticle.

[Fig. 9] Diagrams showing the relations between a wafer crystal axis and a pattern forming direction of a mode of embodiment of the invention, (A) a top plan view of a wafer, and (B) a top plan view of a reticle.

[Description of Reference Numerals and Signs]

- 1 - - - Light Source
- 5 - - - Polarization Control Element
(Adjusting Device)
- 14 - - - Field Stop (Shaping Device)
- 18 - - - Reticle (Mask)
- 19 - - - Reticle Stage (Stage Device)
- 24 - - - Projecting Optical System
- 25 - - - Wafer (Sensitive Substrate)
- 26 - - - Wafer Stage (Stage Device)
- 31 - - - Exposure Field of ViewExposure field
- 32 to 34 - - - Major Pattern
- I_0 to I_4 - - - Illumination Light

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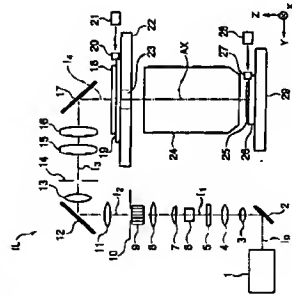
(54) [発明の名称] 露光装置及び露光方法並びにデバイス製造方法

(57) [要約]

【課題】微細パターンの高精度転写を実現する。

【解決手段】光源1及び偏光制御素子5を含む照明光学系1Lにより、X方向に平行な偏光方向の直線偏光を主成分とし、該X方向に長手方向を有するスリット状の照明光1₁が、X方向に延びる主要なラインパターンを含むパターンが形成されたレチクル18に照射される。レチクルステージ19上に保持されたレチクル18と、ウエハステージ26上に保持されたウエハ25は、ステージ19、25によりY方向に沿って移動され、レチクル18のパターンの投影像がウエハ25上に逐次転写される。

【図1】 図1



【特許請求の範囲】

【請求項 1】

マスクに形成されたパターンの像を基板上に転写する走査型の露光装置において、前記マスクと前記基板とを第1方向に沿って相対的に移動するステージ装置と、前記マスクを照明する照明光学系と、前記マスクのパターンを前記基板上に投影する投影光学系とを備えるとともに、前記照明光学系は、前記投影光学系を介して前記基板上に照射される照明光の偏光状態を、前記第1方向に直交する第2方向に平行な偏光方向の直線偏光を主成分とするように、前記マスクを照明することを特徴とする露光装置。

【請求項 2】

前記基板上に照射される照明光はその偏光度が80%以上であることを特徴とする請求項1に記載の露光装置。

【請求項 3】

前記照明光学系は、前記基板に照射される照明光の断面形状を前記第2方向に長手方向を有するスリット状に整形する整形装置を有することを特徴とする請求項1または2に記載の露光装置。

【請求項 4】

前記ステージ装置は、前記マスクに形成されたパターンのうち、ラインパターンの長手方向と前記第2方向とが実質的に平行となるように、前記マスクを保持することを特徴とする請求項1～3のいずれか一項に記載の露光装置。

【請求項 5】

前記照明光学系は、光源からの光を前記第2方向に平行な偏光方向の直線偏光を主成分とする照明光に調整する調整装置を有することを特徴とする請求項1～4のいずれか一項に記載の露光装置。

【請求項 6】

前記照明光学系は、前記投影光学系を介して前記基板に照射される照明光を、前記第2方向に平行な偏光方向の直線偏光を主成分とする照明光とするか、自然光又は円偏光あるいは楕円偏光とするかを選択的に切り替える切り替え機構を有することを特徴とする請求項1～5のいずれか一項に記載の露光装置。

【請求項 7】

照明光のもとで、マスクに形成されたパターンの像を投影光学系を介して基板上に転写する露光装置において、前記基板の上の前記投影光学系の露光視野を、長手方向を有する形状に整形する整形装置と

、前記照明光の偏光方向と前記整形装置との少なくとも一方を調整し、前記基板上の露光視野の長手方向と前記照明光の偏光方向とを互いに平行にする調整装置とを有することを特徴とする露光装置。

【請求項 8】

前記マスクを前記照明光で照明する照明光学系を有し、前記整形装置は、前記照明光学系に設けられることを特徴とする請求項7に記載の露光装置。

【請求項 9】

前記整形装置は、光源からの光を前記基板上の露光視野の長手方向に平行な偏光方向を主成分とする照明光に調整することを特徴とする請求項7に記載の露光装置。

【請求項 10】

前記マスクと前記基板とを第1方向に沿って相対的に移動するステージ装置を有し、前記露光視野の長手方向は、前記第1方向に直交する方向であることを特徴とする請求項7～9のいずれか一項に記載の露光装置。

【請求項 11】

前記照明光学系は、フッ化物結晶で形成される複数の光学素子を有し、

前記複数の光学素子は、前記照明光学系の光軸方向に関して、一部の光学素子の結晶軸の種類と、他の光学素子の結晶軸の種類とが異なることを特徴とする請求項1～110のいずれか一項に記載の露光装置。

【請求項112】

前記一部の光学素子における前記照明光学系の光軸方向に直交する結晶軸に対して、前記他の光学素子における前記照明光学系の光軸方向に直交する結晶軸が、前記照明光学系の光軸を中心軸として相互に回転して配置されていることを特徴とする請求項111に記載の露光装置。

【請求項113】

パターンが形成されたマスクと基板とを第1方向に沿って相対的に移動させつつ、該マスクのパターンを投影光学系を介して該基板上に転写する露光方法であって、

前記基板上に照射される照明光は、前記第1方向に直交する第2方向に長手方向を有するスリット状の照明光であるとともに、前記第2方向に平行な直線偏光を主成分とする照明光であることを特徴とする露光方法。

【請求項114】

前記マスクに形成された前記パターンのうち、ラインパターンの長手方向と前記第2方向とが実質的に平行となるように設定した状態で露光することを特徴とする請求項113に記載の露光方法。

【請求項115】

前記照明光はその偏光度が80%以上であることを特徴とする請求項113又は114に記載の露光方法。

【請求項116】

照明光のもとで、マスクに形成されたパターンの像を投影光学系を介して基板上に転写する露光方法において、

前記基板上の前記投影光学系の露光視野を、長手方向を有する形状に整形し、前記基板上に照射される照明光の偏光方向を前記基板上の露光視野の長手方向と平行にして、前記マスクのパターンの像を前記基板上に転写することを特徴とする露光方法。

【請求項117】

前記マスクに形成された前記パターンのうち、ラインパターンの長手方向と前記露光視野の長手方向とが実質的に平行となるように設定した状態で露光することを特徴とする請求項116に記載の露光方法。

【請求項118】

前記マスクと前記基板とを第1方向に沿って相対的に移動させた状態で露光する際に、前記露光視野の長手方向は、前記第1方向に直交することを特徴とする請求項116又は117に記載の露光方法。

【請求項119】

請求項1～112のいずれか一項に記載の露光装置を用いたデバイス製造方法であって、前記基板として、その表面に垂直な方向が[111]結晶軸にほぼ一致するシリコン結晶基板を用い、前記[111]結晶軸と直交する[11-2]結晶軸またはこれと等価な結晶軸を、前記第2方向又は前記露光視野の長手方向に一致させた状態で前記照明光で前記基板を露光することを特徴とするデバイスの製造方法。

【請求項120】

前記マスクに形成されたゲートパターンを、前記[11-2]結晶軸、またはこれと等価な結晶軸と実質的に平行となるように、前記基板上に露光することを特徴とする請求項19に記載のデバイス製造方法。

【請求項121】

請求項1～112のいずれか一項に記載の露光装置を用いたデバイス製造方法であって、前記基板として、その表面に垂直な方向が[110]結晶軸にほぼ一致するシリコン結晶基板を用い、

前記[110]結晶軸と直交する[00-1]結晶軸又はこれと等価な結晶軸を、前記第

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2方向又は前記露光視野の長手方向に一致させた状態で前記照明光で前記基板を露光することを特徴とするデバイス製造方法。

【請求項22】

前記マスクに形成されたゲートパターンを、前記[00-1]結晶軸又はこれと等価な結晶軸と実質的に平行となるように、前記基板上に露光転写することを特徴とする請求項21に記載のデバイス製造方法。

【請求項23】

請求項1～12のいずれか一項に記載の露光装置を用いたデバイス製造方法であって、前記基板として、その表面層の半導体結晶構造が少なくとも所定の1方向に延んだ半導体ウェハを用い、前記表面層中の電子又はホールの少なくとも一方の移動度が最大となる方向を前記第1方向又は前記露光視野の長手方向に直交する方向に一致させた状態で前記基板を露光することを特徴とするデバイス製造方法。

【請求項24】

前記表面層はシリコン結晶層であることを特徴とする請求項23に記載のデバイス製造方法。

【請求項25】

請求項113～118のいずれか一項に記載の露光方法を用いたデバイス製造方法であって、前記基板として、その表面に垂直な方向が[111]結晶軸にほぼ一致するシリコン結晶基板を用い、

前記[111]結晶軸と直交する[11-2]結晶軸またはこれと等価な結晶軸を、前記第2方向又は前記露光視野の長手方向に一致させた状態で前記照明光で前記基板を露光することを特徴とするデバイス製造方法。

【請求項26】

前記マスクに形成されたゲートパターンを、前記[11-2]結晶軸またはこれと等価な結晶軸と実質的に平行となるように、前記基板上に露光することを特徴とする請求項25に記載のデバイスの製造方法。

【請求項27】

請求項113～118のいずれか一項に記載の露光方法を用いたデバイス製造方法であって、前記基板として、その表面に垂直な方向が[110]結晶軸にほぼ一致するシリコン結晶基板を用い、

前記[110]結晶軸と直交する[00-1]結晶軸又はこれと等価な結晶軸を、前記第2方向又は前記露光視野の長手方向に一致させた状態で前記照明光で前記基板を露光することを特徴とするデバイス製造方法。

【請求項28】

前記マスクに形成されたゲートパターンを、前記[00-1]結晶軸又はこれと等価な結晶軸と実質的に平行となるように、前記基板上に露光転写することを特徴とする請求項27に記載のデバイス製造方法。

【請求項29】

請求項113～118のいずれか一項に記載の露光方法を用いたデバイス製造方法であって、前記基板として、その表面層の半導体結晶構造が少なくとも所定の1方向に延んだ半導体ウェハを用い、前記表面層中の電子又はホールの少なくとも一方の移動度が最大となる方向を前記第1方向又は前記露光視野の長手方向に直交する方向に一致させた状態で前記基板を露光することを特徴とするデバイス製造方法。

【請求項30】

前記表面層はシリコン結晶層であることを特徴とする請求項29に記載のデバイス製造方法。

【発明の詳細な説明】

【0001】

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【発明の属する技術分野】

本発明は、半導体集積回路、液晶表示素子、薄膜磁気ヘッド、その他のマイクロデバイス、又はフォトマスク等をフォトリソングラフ技術を用いて製造する際に使用される露光装置及び露光方法並びにデバイス製造方法に関する。

【0002】

【従来の技術】

半導体集積回路、液晶ディスプレイ等の電子デバイスの微細化に伴って、形成すべきパターンを4～5倍程度に比例拡大して描画した、レチクル（マスクとも呼ぶ）のパターンを、投影露光装置を用いて、ウエハ等の被露光基板上に縮小露光転写する方法が用いられている。

【0003】

転写に使用する投影露光装置は、半導体集積回路の微細化に対応するために、その露光波長を、より短波長側にシフトしてきた。現在、その波長はKrFエキシマレーザーの248nmが主流となっているが、より短波長のArFエキシマレーザーの193nmも実用化段階に入りつつある。そして、さらに短波長の波長157nmのF₂レーザーや、波長126nmのAr₂レーザー等の、いわゆる真空紫外域と呼ばれる波長帯の光源を使用する投影露光装置の提案も行なわれている。

【0004】

また、短波長化のみでなく、光学系の大開口数（NA）化によっても高解像度化は可能である。光学系のより一層の大NA化開発もなされている。なお、高解像度の実現には、投影光学系の収差の低減が必要である。従って、投影光学系の製造工程では、光の干渉を利用した表面収差計測を行ない、収差収差量を露光波長の1/1000程度の精度で計測し、その計測値に基づいて投影光学系の調整を行なっている。

【0005】

このような大NA化や低収差化は、視野が小さい光学系工程実現が容易である。但し、露光装置としては、視野（露光フィールド）が大きいほど、処理能力（スループット）が向上する。そこで、小視野ではあるが大NAの投影光学系を用いて、なおかつ実質的に大きな露光フィールドを得るために、露光中に、マスクとウエハを、その結像関係を維持したまま相対走査するスキャン型露光装置が最近の主流となっている。

【0006】

スキャン型露光装置に使用される投影光学系は、一般的に一方方向に長く、それと直交する方向に短かい真方形型の良像範囲（露光視野）を有する。このような光学系には、反射光学系が使用される場合もあるが、屈折光学系を使用することが一般的である。この場合、上記長方形の露光視野は、円形のレンズの組み合わせからなる屈折光学系の本来の良像範囲である円形から、その円の中心を通る直径を含み、かつその円に内接する長方形とするのが一般的である。その理由は、このような長方形視野が、視野の長辺の長さを最大にでき、最も効率が良いためである。

【0007】

ただし、投影光学系として反射屈折光学系を採用する場合には、投影光学系の良像範囲が円形とならないので、露光視野も円の直径を含む長方形となるとは限らず、円の中心から偏った位置を中心とする長方形となる場合もある。

【0008】

相対走査（スキャン）を行なう方向は、この長辺方向と直交する方向である。従って、長方形短辺方向の投影光学系の視野は、この相対走査によって拡大されるので、短辺方向の視野の狭さが問題となることはない。

【0009】

【発明が解決しようとする課題】

上記のように、スキャン型露光装置で露光される露光エリアは、一方方向については投影光学系の視野によって得られるものであり、その位置に応じて投影光学系の結像性能も変化する。そのため、パターンの転写特性も変化する。

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【0010】

一方、それと直交する方向については、レチクルとウエハの相対走査（スキャン）によって拡大された方向であり、投影光学系の結像性能は、その方向について一様である。

【0011】

ところで、一般的に光学系には、その結像特性を劣化させさせる収差が残存する。投影露光装置用の投影光学系では、他の用途の光学系に比べ収差収差が極めて小さいが、ある程度の収差が残存することは避けられない。

【0012】

これらの残存収差には、転写像を投影光学系光軸から周辺への放射方向にボカす成分（放射方向成分）と、投影光学系光軸を中心とする同心円方向にボカす成分（同心円方向成分）とがあるが、一般的にはこのうち放射方向成分の方が大きい。

【0013】

放射方向成分の収差は、コマ収差や倍率の色収差である。コマ収差は、設計上も製造誤差の点からその補正が難しく、これを完全に無くすることは困難である。倍率色収差の補正には、レンズの2次スベクトル補正のための高価なレンズ材料が大量に必要であり、その完全な補正によりレンズ価格が極めて上昇してしまう。一方、光源であるレーザー（エキシマレーザー等）の波長幅を狭くすること（狭帯化）で、色収差の影響を低減することも可能ではあるが、レーザーの狭帯化によりその出力は低下し、従ってウエハ面上での露光光強度が低下してしまう。従って、照明時間を長くする必要があり、露光装置の処理能力（スループット）が低下し、その生産性が低下してしまうことになる。また、レーザー帯帯化に必要な光学素子にも寿命があるため、その定期的な交換が必要になりレーザーランニングコストが上昇してしまう。

【0014】

本発明は、このような課題に対してなされたものであり、基板上に転写すべきパターンのうち重要なパターンについての高精度転写を可能とするとともに、倍率色収差や一部のコマ収差等の同心円方向成分の収差が残存する光学系を使用しても、従来と同等かそれ以上に微細なパターンの転写を可能とする露光装置及び露光方法並びにデバイス製造方法の実現を目的とする。

【0015】

【課題を解決するための手段】

以下、この項に示す説明では、本発明を、実施形態を表す図面に示す参照符号に対応付けで説明するが、本発明の各構成要件は、これら参照符号を付した図面に示すものに限定されない。

【0016】

上述した課題を解決するため、本発明の第1の観点によると、マスク（18）に形成されたパターンの像を基板（25）上に転写する走査型の露光装置において、前記マスクと前記基板とを第1方向（Y方向）に沿って相対的に移動するステージ装置（19、26）と、前記マスクを照明する照明光学系（11）と、前記マスクのパターンを前記基板上に投影する投影光学系（24）とを備え、かつ前記照明光学系は、前記投影光学系を介して前記基板上に照射される照明光の露光状態を、前記第1方向に直交する第2方向に平行な露光方向の直線露光を主成分とするように、前記マスクを照明する機能を有する露光装置が提供される。ここで、「直線露光を主成分とする」とは、当該照明光が当該直線露光のみを成分とする完全露光、又は自然光若しくは他の露光をも含む部分露光をいう。当該照明光が部分露光である場合の露光度としては、80%以上とすることが望ましい。「露光度」とは、当該部分露光の全エネルギーに占める当該直線露光のエネルギーの割合をいう。また、「露光方向」とは、光の電場ベクトルの方向をいう。

【0017】

本発明によると、マスクのパターンが基板上に転写される際に、基板上に照射される照明光（露光光）の露光状態が、移動方向としての第1方向に直交する第2方向に平行な露光方向の直線露光を主成分とする露光状態として、マスクのパターンの基板上に露光転写するよう

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にしたので、マスクに形成されたパターンのうち、当該第2方向に沿う方向に延びるライエンパターンについての投影像のコントラストを高くすることができ、微細なパターンの高精度転写が可能となる。

【0018】

本発明において、前記照明光学系(11)は、前記基板上に照射される照明光の断面形状を前記第2方向に長手方向を有するスリット状(長方形、短冊状)に整形する整形装置(114)を有することができ、これにより、投影光学系の幾何収差による悪影響を緩和することができ、さらに高精度転写が可能となる。なお、前記マスクと前記基板は結像関係にある(すなわちマスクのパターンが投影される)ので、前記基板上において照明光の断面形状をスリット状にすることは、前記マスク(18)に照射する照明光(14)の断面形状をスリット形状とすることで実現できる。

【0019】

これらの場合において、前記ステージ装置(19, 26)は、前記マスク(18)に形成されたパターンのうち、ライエンパターン(32~34)の長手方向と前記第2方向(X方向)とが実質的に平行となるように、前記マスクを保持することができ、前記ライエンパターンが互いに異なる方向(例えば、互いに直交する方向)に2種類以上ある場合には、当該ライエンパターンのうち、特に高精度転写を行うべき主要なライエンパターンの長手方向と前記第2方向とが実質的に平行となるように、前記マスクを保持することが望ましい。上述したように、第2方向に沿う方向に延びるライエンパターンについての露光精度を高くすることができ、主要なライエンパターンを当該第2方向に沿うように極めて高精度に設定することにより、当該主要なライエンパターンの露光精度を高くすることができ、

【0020】

本発明において、前記照明光学系(11)は光源(1)から供給された光(10)を、前記投影光学系(24)を介して、前記第2方向(X方向)に平行な偏光方向の直線偏光を主成分とする照明光として前記基板(25)上に照射するための調整装置(5)を有する構成とができる。照明光学系(11)に光を供給する光源(1)が、特定の方向に平行な偏光方向の直線偏光を主成分とする光を射出する場合には、前記調整装置(5)としては、前記基板(25)に照射される照明光の当該直線偏光の偏光方向が、前記第2方向に沿うようにその偏光面を回転する偏光回転装置(たとえば2分の1波長板)を用いる。但し、そのような調整装置(5)を用いずに、該光源(1)と該照明光学系(11)との光学系位置関係を適宜設定して、前記第2方向に平行な偏光方向の直線偏光を主成分とする照明光を、該投影光学系を介して該基板に照射するようにしても良い。また、照明光学系(11)に光を供給する光源(1)が、自然光その他の偏光(円偏光、楕円偏光)を射出する場合には、前記調整装置(5)として、該光源からの光を前記第2方向に平行な偏光方向の直線偏光を主成分とする照明光に調整する直線偏光装置(例えば、直線偏光子、4分の1波長板)を用いる。

【0021】

本発明において、前記照明光学系(11)は、前記投影光学系(24)を介して前記基板(25)に照射される照明光を、前記第2方向に平行な偏光方向の直線偏光を主成分とする照明光とするか、自然光又は円偏光あるいは楕円偏光とするかを選択的に切り替える切り替え機構を有することができ、これにより、露光転写するパターンの内容に応じて、適宜な照明光を選択することができ、

【0022】

上述した課題を解決するため、本発明の第2の観点によると、照明光(14)のもとで、マスク(18)に形成されたパターン像を投影光学系(24)を介して基板(25)上に転写する露光装置において、前記投影光学系(24)の露光視野を、長手方向を有する形状に整形する整形装置(114)と、前記照明光(14)の偏光方向と前記整形装置(14)との少なくとも一方を調整し、前記基板上における前記投影光学系の露光視野の長手方向と、前記基板に照射される前記照明光の偏光方向を、互いに平行にする調整装置(5)とを備えた露光装置が提供される。

【0023】

本発明の露光装置は、前記マスクを前記照明(14)光で照明する照明光学系(11)を備え、前記整形装置(114)は、前記照明光学系(11)に設けられるようにすることができ、

【0024】

また、本発明において、前記調整装置(5)は、光源からの光を前記基板上において、前記投影光学系の前記露光視野の長手方向に平行な偏光方向の直線偏光を主成分とする照明光に調整することができ、

【0025】

また、本発明の露光装置は、前記マスク(18)と前記基板(25)とを第1方向(Y方向)に沿って相対的に移動するステージ装置(19, 26)を有し、前記露光視野の長手方向は、前記第1方向に直交する方向(X方向)であるようにすることができ、

【0026】

本発明の第3の観点によると、本発明の第1又は第2の観点に係る露光装置において、前記照明光学系は、フッ化物結晶で形成される複数の光学素子を有し、前記複数の光学素子は、前記照明光学系の光軸方向に関して、一部の光学素子の結晶軸の種類と、他の光学素子の結晶軸の種類とが異なることを特徴とする露光装置が提供される。

【0027】

この場合において、前記一部の光学素子における前記照明光学系の光軸方向に直交する結晶軸に対して、前記他の光学素子における前記照明光学系の光軸方向に直交する結晶軸が、前記照明光学系の光軸を中心軸として相互に回転して配置するようにできる。

【0028】

なお、「一部の光学素子の結晶軸の種類と、他の光学素子の結晶軸の種類とが異なる」とは、当該一部の光学素子の照明光学系の光軸方向の結晶軸が例えば[111]結晶軸である場合に、当該他の一部の光学素子の照明光学系の光軸方向の結晶軸が[111]結晶軸以外の結晶軸(例えば[100]結晶軸)であることをいう。

【0029】

複数の光学素子を上記のように所定の関係で配置することにより、該光学素子が有する複屈折性を補正しない相殺することができ、当該複屈折性による照明光の偏光方向や偏光状態に対する悪影響を小さくすることができ、

【0030】

上述した課題を解決するため、本発明の第4の観点によると、パターンが形成されたマスク(18)と基板(25)とを第1方向(Y方向)に沿って相対的に移動させつつ、該マスクのパターンの投影光学系を介して該基板上に転写する露光方法において、前記基板上に照射される照明光が、前記第1方向に直交する第2方向に長手方向を有するスリット状の照明光であるとともに、前記第2方向に平行な直線偏光を主成分とする照明光であるようにした露光方法が提供される。この場合において、前記マスクに形成された前記パターンのうち、ライエンパターンの長手方向と前記第2方向とが実質的に平行となるように設定することが望ましい。

【0031】

ここで、「直線偏光を主成分とする照明光」とは、当該照明光が当該直線偏光のみを成分とする完全偏光、又は自然光若しくは他の偏光をも含む部分偏光をいう。当該照明光が部分偏光である場合の偏光度としては、80%以上とすることが望ましい。「偏光度」とは、当該部分偏光の全エネルギーに占める当該直線偏光のエネルギーの割合をいう。また、「偏光方向」とは、光の電場ベクトルの方向をいう。

【0032】

本発明によると、移動方向としての第1方向に直交する第2方向に平行な偏光方向の直線偏光を主成分とし、該第2方向に長手方向を有するスリット状の照明光を用いて露光するようにしたので、マスクに形成されたパターンのうち、当該第2方向に沿う方向に延びるライエンパターンについての投影像のコントラストを高くすることができるとともに、マス

ステップ移動することによって、ウエハ25上の全面に設定された複数のシヨット領域にレチクルパターンの投影像をそれぞれ転写するために、ウエハ25をXY方向に順次ステップ移動させつつ、Y方向への走査（スキヤン）露光を繰り返すようにしている。

[0046]

KrF（クリプトンフッ素）エキシマレーザ（波長248nm）、ArF（アルゴンフッ素）エキシマレーザ（波長193nm）、F₂（フッ素分子）レーザ（波長157nm）等の光源1から射出された照明光I₀は、照明光学系I₁に供給される。

[0047]

照明光学系I₁の構成は以下の通りである。光源1から供給された照明光I₀は、偏光ミラー2及び整形光学系3、4により導かれ、偏光制御要素5に入射する。偏光制御要素5の詳細については後述する。

[0048]

偏光制御要素5を通過した照明光I₁は、フライアイレンズや回折格子等の第1の照度均一化部材6に入射する。第1の照度均一化部材6を射出した光束は、リレーレンズ7、8を経て、フライアイレンズ等の第2の照度均一化部材9に入射する。照度均一化部材9の射出側面には、照明開口絞り（α絞り）10が設けられている。照明開口絞り10として、半径が可変な円形絞り（虹彩絞り）、輪帯形状の絞り、複数の開口部を有する変形照明絞り等を使用することができ、これらは回転可能なレボルバル上に配置され、該レボルバルが適宜に回転・位置決めされることにより、選択的に配置することができるようにしている。

[0049]

照明開口絞り10を射出した光束は、リレーレンズ11、折り曲げミラー12、リレーレンズ13を経て視野絞り14に至る。視野絞り14（整形装置）は、レチクル18上の照明視野を制限する装置ないし部材である。

[0050]

本露光装置はスキヤン型露光装置であり、露光に際してレチクル18及びウエハ25がY方向にスキヤンするので、レチクル18上での照明視野は、図中X方向に長くY方向に短いスリット形状（ここでは、長方形）とする。このため、視野絞り14の形状は、折り曲げミラー17の反射特性を考慮して、図中X方向に長く2方向に短い長方形となっている。なお、スリットの幅を調整するため、視野絞り14の2方向の両端を規定する絞りは、それぞれ2方向に移動可能な構成とすると一層好ましい。X方向については同様である。視野絞り14を通過した光束は、リレーレンズ15、16と折り曲げ折り曲げミラー17を経て、レチクル18に照射される。

[0051]

偏光制御要素5は、照明光I₀の偏光状態を制御するための光学要素であり、その偏光状態を所定の状態に設定する。所定の状態とは、レチクル18上に照射される照明光が概ね直線偏光であり、その偏光方向（光の電場ベクトルの方向）が図中X方向になる状態である。図1に示した装置では、偏光制御要素5の射出位置での偏光方向もX方向になるように設定することになる。

[0052]

通常の投影光学系は、その内部に照明光（露光光）の偏光方向を変化させるような部材（基板板や偏光ビームスプリッター）を含まないもので、上記の様にレチクル18上照射される照明光の偏光状態を、図中X方向（すなわち投影光学系視野の長手方向）と平行にすれば（一致せれば）、マスクおよび投影光学系を介してウエハに照射される照明光（露光光）の偏光状態も、投影光学系視野の長手方向と概ね平行になる。従って、以下の説明は、レチクルに照射される照明光の偏光状態と、ウエハに照射される照明光（結像光）の偏光状態とは、等価であることを前提として行なう。

[0053]

上述のエキシマレーザ光源やフッ素レーザ光源では、その射出光（照明光I₀）が概

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ね直線偏光になる。そこで、この直線偏光の偏光方向を上記所定の方向に一致させるために、例えば、水晶（二酸化珪素結晶）やフッ化マグネシウム結晶等の複屈折性を有する光学材料よりなる1/2波長板を、所定の方向で挿入する。なお、光源1と照明光学系I₁との光学的な相対位置関係において、光源1から照明光学系I₁に供給される照明光I₀の偏光方向がはじめから上記所定の方向（X方向）と一致している場合には、あえてこのような偏光制御要素5を設けなくても良い。

[0054]

なお、光源1が、ランプやランダム偏光レーザの様に直線偏光以外の光束を発する場合には、偏光制御要素5として、上記所定の方向の直線偏光のみを透過する偏光フィルターや偏光ビームスプリッタを使用する。

[0055]

ここで、レチクル18に照射する照明光は、完全な直線偏光である必要は必ずしもなく、照明光強度の大部分（例えば、80%程度以上）を所定の直線偏光とすれば、本発明の効果は発揮できる。従って、上記偏光フィルターや偏光ビームスプリッタを用いる場合には、その偏光選択比は、80%程度以上であれば十分である。また、狭帯化を行なわないフッ素レーザを光源とする場合には、照明光I₀は、ある程度の直線偏光になり、それと直交する直線偏光も含まれるが、同様の理由により、その照明光に対してそれ以上の直線偏光化を行なわなくても良い。

[0056]

図2はレチクルステージ19上に載置された状態におけるレチクルの一例を示す平面図である。図2に示すように、レチクル18のパターンエリア30内には主要なラインパターンとして、パターン32、33、34が描画されている。これらのパターン32、33、34は、例えば、トランジスタゲート等の線幅自体が細く、要求される線幅均一性が厳格なパターン、即ち高精度転写が必要なパターンであり、特定の方向に沿って形成されている。パターンエリア30内には他のパターン（図示省略）も描画されており、当該他のパターンは、例えば、該トランジスタゲートの端部に設けられる配線パターン、トランジスタゲートであったり動作速度が遅くてもよいパターン等の比較的線幅が太く、線幅均一性が緩いパターンであり、パターン32、33、34とは異なる方向に沿って形成されている。

[0057]

本実施の形態では、図2に示されているように、レチクル18を、その主要なパターン32、33、34の延びている方向がX方向に略平行となるようにレチクルステージ19上に吸着保持せしめている。すなわち、転写すべきパターンのうち、その線幅が微細かつその線幅均一性が非常に重要になるパターン32、33、34について、その方向をX方向に設定している。

[0058]

図2において、パターンエリア30中の破線で示した領域31は、投影光学系24の露光視野に相当する領域であり、投影光学系24の良像範囲40に内接するとともに、その中心は投影光学系24の光軸AXに一致している。但し、投影光学系24の露光視野は投影光学系24の良像範囲40に対して偏心して設定される場合があり、この場合には、露光視野の中心と、投影光学系24の光軸AXとは一致しない。照明光学系I₁によりレチクル18に照射される照明光I₁は、この領域に照射される。この照明光I₁の偏光状態は、図中に記号Eで示した通りX方向に偏光方向を有する直線偏光を主成分とする。

[0059]

露光に際して、レチクル18及びウエハ25はその結像関係を保ったままY方向に相対走査（スキヤン）されるので、図2の状態では露光視野31内にないパターン（パターン34等）もこの走査により順次露光視野31内に入り、ウエハ25に転写される。

[0060]

次に、本発明の特徴の一つであるパターン方向と露光視野長辺方向の関係及び照明光偏光方向の関係について説明する。

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【0061】

図3 (A) ~ (C) 及び図4 (A) ~ (D) は、パターン方向と偏光方向の関係を示すための図であり、図3 (A) 及び図4 (A) は、図中X方向に伸びるパターン36に、それぞれ偏光方向E₁がX方向に一致する直線偏光I_{4,1}と、偏光方向E₂がY方向に一致する直線偏光I_{4,2}とが照射される場合を表わしている。

【0062】

X方向に伸びるパターン36に回折された照明光I_{4,1}、I_{4,2}は、それぞれ+Y及び-Y方向に回折光を生じさせる。これらの回折光は、図3 (A) では、0次回折光D01、-1次回折光DM1、+1次回折光DPM1で示され、図4 (A) では、0次回折光D02、-1次回折光DM2、+1次回折光DPM2で示されている。各回折光の偏光状態は、各照明光I_{4,1}、I_{4,2}の偏光状態が保存されるので、投影光学系24の端面EP上において、図3 (A) 中の回折光D01、DM1、DPM1はX方向の直線偏光になり、図4 (A) 中の回折光D02、DM2、DPM2はY方向の直線偏光になる。

【0063】

このような回折光（上述のようにX方向に延びるパターン（X方向のパターン）からのY方向に広がった回折光）は、投影光学系24の結像作用により、端面EPを通過後に、その進行方向が再びY方向に回折され、ウエハ25上で再び集光して、ここにパターン36の像である干渉縞が形成される。そして、この干渉縞がウエハ25に照射（照明）され、ウエハ表面上に塗布されたフォトリソレジスト上に像が記録される。

【0064】

上記光束の回折に併せて、その偏光方向が光束の進行方向と直交する方向に回転する。これは電場方向が常に光の進行方向と直交するという光の物理法則に従うものである。

【0065】

図4 (A) 中の回折光DM2、DPM2は端面EP上ではY方向の直線偏光であるが、その偏光方向は回折光DM2、DPM2の回折に応じて変化する。図4 (B) は、図4 (A) のウエハ25付近の拡大図であり、回折光DM2、DPM2の偏光方向は、各光束の進行方向に直交する方向となり、Y方向からは、ずれている。但し、回折光D02の進行方向は-Z方向であるため偏光方向はY方向のまま維持されている。

【0066】

このような光束による干渉縞（像）の強度分布は、各偏光（電場）のY方向成分の和の自乗（エネルギー）（図4 (C) 中の実線で示す強度分布IM2）と、各偏光（電場）のZ方向成分の和の自乗（エネルギー）（図4 (C) 中の破線で示す強度分布IM3）との和であり（X成分の和は0である）、図4 (D) の強度分布IM4となる。しかしこのとき、回折光DM2、DPM2の電場のZ方向成分は両偏光の角度の関係から両者の符号が反転するため、その強度分布IM3は、電場のY方向成分が形成した像の強度分布IM2とは位相がずれ、そのコントラストを低下させてしまう。

【0067】

従って、図4 (A) に示したように、X方向のパターンを偏光方向がY方向である直線偏光で照明すると、ウエハ上に照射される照明光（各回折光）の偏光方向が互いに平行でないために、その投影像のコントラストが低下してしまい、微細なパターンの転写には適さない。

【0068】

これに対し、図3 (A) 中の回折光D01、DM1、DPM1のように、端面EP上でX方向に偏光方向を持つ光束の偏光方向は、光束の進行方向がY方向に回折してもX方向に維持される。そして、図3 (B) に示されているように、ウエハ25上には、偏光方向が全てX方向に揃った回折光D01、DM1、DPM1が照射され、干渉縞が形成される。この干渉縞強度分布は、電場のX方向成分の和の自乗により求まり（Y、Z成分の和は0である）、図3 (C) 中の強度分布IM1の通りとなる。これは、図4 (A) の場合と異なり符号の反転した成分がないため、そのコントラストが高いことを意味する。

【0069】

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従って、図3 (A) に示したように、X方向のパターンを、ウエハ上に照射される照明光（各回折光）の偏光方向がすべてX方向に平行になるように、偏光方向がX方向である直線偏光で照明すると、その投影像のコントラストは高く、微細なパターンの転写に適する。

【0070】

次に、パターン方向と露光視野長辺方向の関係について、図5を用いて説明する。図5には、投影光学系24の露光視野31が示されている。露光視野31の形状は、その長辺がX方向に沿い、短辺がY方向に沿った長方形となっている。そして、その中心Cは、前述の通り投影光学系24の光軸AXと一致する場合が多い。

【0071】

このような露光視野31上のX方向の端に近い点39上の結像特性である点像強度分布は、原理的な回折限界及び投影光学系24の残存収差の影響で、投影光学系24の放射方向及び同心円方向（図5中の点39に対しては、それぞれX方向、Y方向（一致）に、広がり（ボケ）を持ってしまう。図中の点像強度分布60、61は、それぞれ点39の位置での点像強度分布のX方向断面（放射方向断面）及びY方向断面（同心円方向断面）を表わしている。このように点像分布の広がり幅は、残存収差の影響で、放射方向の方が同心円方向より大きくなるのが一般的である。残存収差には、各種収差があるが、このうちコマ収差と楕円率色収差が、放射方向の点像分布の広がりを、同心円方向への広がりより大きくする主因である。

【0072】

このうちコマ収差は、設計上も製造誤差の点でも完全に除去することは難しい。また、楕円率色収差は、投影光学系24を構成するレンズの材料に、色収差除去に好適な材料（例えば、螢石）を多用するなり、投影光学系24を、凹面鏡を組み込んだ反射屈折光学系にする等の対策を施すことで除去は可能であるが、そのいずれの手法でも投影光学系の製造コストが上昇してしまう問題がある。

【0073】

投影光学系には、このような収差が残存するため、露光視野31の周辺では、露光視野31の長辺方向に平行なパターン37の方が、露光視野31の長辺方向に垂直なパターン38に比べて残存収差の影響を受けにくく、より微細なパターンの転写が可能になる。

【0074】

本実施の形態では、転写すべきパターンのうち、その線幅が微細かつその線幅均一性が非常に重要になるパターンについて、その方向をX方向（パターン37の方向）に設定している。その転写像は、上記放射方向の収差の影響を受けなくなる。従って、従来と同じ投影光学系を使用しても、より微細なパターンを解像することが可能になる。また、照明光学系11Lから照射される照明光も、上記のようなX方向（露光視野31の長辺方向に平行な方向）のパターンに最適な照明であるX方向の直線偏光であるため、従来に比べ、より一層微細なパターンを解像することができ。

【0075】

あるいは、露光するパターンの微細度が従来と同程度で良いなら、使用する投影光学系24の放射方向の残存収差の許容値を、従来の投影光学系に比べて緩めることができる。特に倍率収差許容値の緩和により、投影光学系のコストダウンを図ることができるので、安価な投影露光装置を提供することが可能になる。

【0076】

また、投影光学系24の色収差補正はそのまま、光源1のスペクトル幅を緩和することでもできる。狭帯化レーザーの場合、スペクトル幅の緩和はレーザー装置の簡素化を意味し、レーザー出力の増大と狭帯化素子寿命の延長をもたらす。露光装置の処理能力の向上と、狭帯化素子のランニングコストひいては露光装置のランニングコストの削減を可能とする。

【0077】

ところで、上述した実施の形態においては、レチクル18にX方向に平行な偏光方向を主

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成分とすると照明光 I_1 を照射するようにしたが、露光するパターンによっては、レチクル118上に照射される照明光の偏光状態(自然光)又は円偏光ないし楕円偏光とすることが好ましい場合もある。そこで、本実施の形態においては、偏光制御素子5を、着脱可能な構成とし、あるいは照明光の進行方向を回転軸として回転可能な構成とすることが望ましい。

【0078】
例えば、光源1が概ね直線偏光の光束を束するレーザ光源であり、偏光制御素子5として1/2波長板を使用する場合には、図6に示すように、偏光制御素子5を2枚の1/4波長板511、52から構成し、照明光 I_0 の進行方向を回転軸としたそれぞれの回転によつて、射出される光束 I_1 を直線偏光としたり円偏光としたりすることができ。

【0079】
即ち、射出光 I_1 を直線偏光とする場合には、1/4波長板511、52の互いの長軸方向を揃え、共に、その方向を入射光 I_0 の偏光方向と射出光 I_1 の所望の偏光方向の中間の方向に設定すれば良く、射出光 I_1 を円偏光とするには、光源側の1/4波長板511の長軸方向を入射光 I_0 の偏光方向と一致させ、他方の1/4波長板52の長軸方向を、上記偏光方向に対して45度回転した方向に設定すれば良い。

【0080】
また、光源1が非偏光を射出するものである場合には、偏光制御素子5としての偏光フィルターや偏光ビームスプリッターを装着すること、レチクル118上に照射される照明光 I_1 の偏光状態を変とすることができ。

【0081】
なお、本実施の形態では、マスクと基板とが相対移動した状態でマスクのパターンを基板へ転写し、基板を順次ステップ・アンド・スキャン方式の露光装置に用いて、マスクと基板とが静止した状態でマスクのパターンを基板へ転写し、基板を順次ステップ移動させるステップ・アンド・リビート方式で露光してもよい。この、ステップ・アンド・リビート方式が適用される露光装置は、ステップ・アンド・スキャン方式の露光装置に対し、マスクと基板とを互いに静止させた状態で露光を行う点で異なり、その他の構成は、ステップ・アンド・スキャン方式の露光装置と同じ構成にすることができる。このステップ・アンド・リビート方式の露光装置においては、本発明を適用する場合には、マスクのパターンを照明光の偏光方向を露光制御素子5で調整すると共に、視野絞り14を照明光学系の光軸周りに回転させて、投影光学系の露光視野の周辺方向と照明光の偏光方向とを互いに平行することも可能である。また、光源から供給される照明光の偏光方向がはじめから所定の方向と一致している場合には、偏光制御素子5を設けずに、視野絞り14を回転させるだけでもよい。

【0082】
なお、露光装置の光源を、F₂レーザ等の真空紫外光とする場合には、使用するレンズ等の透過光学部材の材料は真空紫外光に対する透過性の高い、蛍石等のフッ化珪素結晶か、フッ素添加の石英のような、いわゆるモディファイド石英を使用する。また、光路については、真空紫外光に対する透過率の高い希ガスや窒素ガスでガス置換して使用する必要がある。

【0083】
ところで、F₂レーザを光源とする露光装置では、透過率の関係上、照明光学系や投影光学系に採用されるレンズとして使用可能な材料は、実質的に蛍石に限定される。蛍石は立方晶系に属する結晶であり、従来は結晶固有の複屈折は発生しないと考えられていたが、2001年の5月のInternational SEMTECH (Semiconductor Manufacturing Technology Institute)において主催した157nmシンポジウム(米国カリフォルニア州アナハイムで開催)において、真空紫外域では、蛍石も結晶固有の複屈折を有することが、NIST (National Institute of Standards and Technology)

g_y : 米国国立標準技術研究所)より発表された。

【0084】
従来のランダム偏光照明を使用する露光装置においては、照明光学系を構成するレンズ材の複屈折は、最終的な結像性能には殆ど影響しない。従ってこれまで、照明光学系に配置される蛍石レンズの固有複屈折が問題にされることもなかった。

【0085】
しかしながら、本発明のように、マスクパターンを直線偏光で照明するようにした場合、照明光学系内の蛍石レンズの固有複屈折に伴う偏光方向の回転が、問題となる恐れがある。すなわち、蛍石レンズの固有複屈折が、1/2波長板や1/4波長板のように作用して、マスクパターン面を照明する照明光の偏光方向が、所望の方向からズレてしまう恐れがある。また、マスクパターン面内の場所に応じて、照明光の偏光状態が異なってくる恐れもある。従って、F₂レーザを照明光源とし、照明光学系に蛍石のような結晶材料を用いた露光装置においては、以下のような対策を講じることが望ましい。

【0086】
すなわち、照明光学系の中に配置される蛍石レンズ(S枚)のうち、所定の何枚か(A枚とする)は、その光軸を結晶軸の[111]軸と一致させ、かつそのうちの所定枚(a枚とする)のレンズと残りのレンズ(A-a枚)とは、光軸を回転中心として、その結晶方向が互いに60度回転するように配置し、残るB枚(=S-A枚)のレンズは、その光軸を結晶軸の[100]軸と一致させ、かつそのうちの所定枚(b枚)のレンズと残りのレンズ(B-b枚)とは、光軸を回転中心として、その結晶方向が互いに45度回転するように配置するなどの対策を施すことが望ましい。

【0087】
図7は、一例として4枚の照明光学系内のレンズに対して上記対策を施した場合を示しており、照明光学系の光軸LAXに沿って並ぶ4枚のレンズL11、L2、L3、L4は、いずれも蛍石からなるレンズである。このうち4枚のレンズL11、L2は、その光軸(照明光学系の光軸LAXと一致)が蛍石結晶の[100]軸と一致するレンズであり、かつ両者のレンズ面内方向(光軸LAXと直交する面内)での蛍石結晶の結晶軸([010]軸及び[001]軸)は、図示した通り45度回転した関係になっている。

【0088】
また、レンズL3、L4は、その光軸(照明光学系の光軸LAXと一致)が蛍石結晶の[111]軸と一致するレンズであり、かつ両者のレンズ面内方向(光軸LAXと直交する面内)での蛍石結晶の結晶軸([0-11]軸、[-110]軸、及び[-101]軸)は、図示した通り60度回転した関係になっている。

【0089】
照明光学系にこのような、対策を施すことで、マスクパターン面での照明光の偏光状態を、所望の直線偏光にすることができ、本発明の効果を十分に発揮することが可能となる。

【0090】
なお、蛍石が投影光学系内のレンズに採用された場合において、固有複屈折が投影光学系の結像性能に与える影響については、使用する各蛍石レンズの光軸をどの結晶軸と一致させるか、あるいは、各レンズを光軸を回転中心として何度回転させて配置するかを最適化することにより解決可能なことが、2002年3月のSPIE (International Society for Optical Engineering Micro lithography Symposium)における本願発明者等の論文等で報告されている。

【0091】
なお、上述した実施形態では、投影光学系の内部には、照明光(露光)の偏光方向を変化させるような部材(波長板や偏光ビームスプリッター)を含まないことを前提として説明してきたが、ある種の反射屈折光学系では、その中に波長板や偏光ビームスプリッターなどの偏光状態変換部材を含むものも存在する。この場合にも、投影光学系の露光視野はスリット状となることが多い。ただし、レチクルに照明される照明光の偏光状態と、ウエ

ハ側に照射される照明光（露光光）の偏光状態は、上記露光状態変更部材により変更される、両者での露光視野スリット長手方向と偏光方向との関係が、一致しなくなる場合もある。

【0092】

本発明を、そのような投影光学系を有する露光装置に適用する場合には、レチクルに照射する照明光の偏光状態を、上記投影光学系を経て最終的にウエハ面に照射される照明光（露光光）の偏光状態が、ウエハ面での露光視野スリットの長手方向と平行になるように設定することが望ましい。逆に、レチクル側での照明光を、レチクル側の露光視野スリットの長手方向と平行になるように設定しても、投影光学系による偏光状態が上記露光状態変更部材により変更されると、ウエハに入射する照明光（露光光）の偏光状態が、好ましくない状態になるため、本発明の効果を得ることはできない。

【0093】

ところで、上述した実施形態においては、投影光学系とウエハの間の空間には、気体（空気が又は紫外線に対する吸収の少ないガス）が存在するとして、本発明はこれに限定されるものではなく、投影光学系とウエハの間の空間に、液体が満たされたものであっても良い。これは、すなわち浸没光学系であり、ウエハに照射される照明光（露光光）の波長を上記液体の屈折率分の1だけ縮小することにより、露光装置の解像度の一層向上を実現するものである。

【0094】

投影光学系では、同一波長において同一ピッチのパターンを露光する際の照明光（露光光）の上記液体中の0次光と1次光のなす角の正弦値は、浸没でない光学系の場合に比べて、上記液体の屈折率分の1だけ縮小される。これは、逆に言えば、同様な構成の投影光学系においても、その開口数を上記液体の屈折率分だけ拡大することができることを意味し、これが上記解像度向上の主因である。

【0095】

ただし、真隣にパターン間の溝壁が形成されるフォトレジスト中においては、浸没光学系であっても浸没でない通常の光学系であっても、フォトレジストの屈折率が同じであるため、同一波長において同一ピッチのパターンを露光する際の照明光（露光光）の0次光と1次光のなす角の正弦値は、両者で同一となる。従って、通常の光学系に比べ、一層微細な（ピッチの細かい）パターンを露光すべき浸没光学系においては、レジストに照射される照明光（露光光）の偏光状態が好ましくなく、レジスト中の各波長の回折光（露光光）の偏光方向のずれが大きいために、一層の像コントラストの低下が生じることになる。従って、浸没投影光学系に本発明を適用すると、従来の浸没でない投影光学系に本発明を適用した場合に比べて、一層の効果が得られることになる。

【0096】

次に、現在の半導体集積回路の主役であるC-MOS-LSIでは、ウエハ表面が結晶の＜100＞面に一致するシリコン結晶の表面に電子デバイスが形成したもののが一般的である。C-MOS-LSIでは、シリコンウエハの表面に、n-MOSのトランジスタとp-MOSのトランジスタの対を形成するが、上記のように表面が結晶の＜100＞面であるウエハを使用すると、p-MOSトランジスタのホール（正孔）の移動度が低いという問題がある。

【0097】

一方、ウエハ表面を結晶の＜111＞面に一致させたシリコンウエハ（すなわち表面に垂直な結晶軸が[111]結晶軸であるウエハ）では、その＜111＞面内の[1-10]軸方位、及びこれと等価な＜111＞面内の方位への、電子及びびホールの移動度が大きい。C-MOS-LSIのC-MOS-LSIの一層の高速動作が可能となる。ここで等価な方位とは、各指数の順序が入れ替わった方位およびそれらから少なくとも1つの増数の符号を反転させた方位であり、その中で上記の通り＜111＞面内に存在する方位は、[-110]軸方位、[10-1]軸方位、[-101]軸方位、[01-1]軸方位、[0-11]軸方位、[0-11]軸方位となる。

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【0098】

なお、[1-10]軸又はこれに等価な軸は、結晶の＜111＞面内で、それぞれ120度の角度で交わる3方位である。従って、この方位に直交する＜111＞面内の方向、すなわち[11-2]結晶軸やこれと等価な＜111＞面内に存在する軸（例えば、[1-21]結晶軸、[2-1-1]結晶軸等）に平行に、ゲートパターンの長手方向を形成すると、そのゲートを含むMOSトランジスタ内の電子及びびホールの移動方向を、移動度の大きな[1-10]軸方位や[-110]軸方位と一致させることができ、C-MOS-LSIの一層の高速動作が可能となる。

【0099】

ここで、実際には、正方形の外形のレチクルに対して、その辺と平行でない微細パターン（描画精度（パターン幅均一性）は、平行な微細パターンに対して劣るため、レチクル上のパターン方位は、レチクル外形の正方形の辺の向きに揃えることが好ましい。しかし、上記の結晶の＜111＞面内で、それぞれ120度の角度で交わる3方位の[1-10]軸又はこれに等価な軸のうち1つを、レチクル外形の1つに一致させると、他の2方位は、レチクルパターンの形成精度上、好ましくない方位になってしまう。従って、表面に垂直な結晶軸が[111]軸であるウエハを使用してより高速なC-MOS-LSIを実現する場合、実質的に使用可能なゲートパターンの長手方向は、1方向（[-112]軸及びこれと等価な軸方向の中のいずれか1方向）に揃える必要がある。以下、この点について考察する。

【0100】

図8（A）は、表面に垂直な結晶軸が[111]軸であるシリコンウエハのウエハ表面内におけるシリコン結晶の方位を表わす図である。すなわち、ウエハ表面は、シリコン結晶の＜111＞面に一致している。図示した通り、[111]軸は、紙面に垂直（すなわちウエハ表面に垂直）な方向であり、ウエハ表面内には、電子及びびホールの移動度が大きな方位である[110]軸と等価な結晶軸（[0-11]軸、[-110]軸、及び[-101]軸）が120度の角度間隔で並んでいる。なお、同図ではウエハの回転方向を所定の方向に設定して、[-110]軸と図面のY軸が一致するものとしている。

【0101】

MOSトランジスタの動作速度を速めるには、トランジスタ内の電子及びびホールの移動方向を、上記[110]軸又はこれと等価な軸方向に一致させることが望ましいので、ゲートパターンの長手方向としては、図8（A）にゲートパターンG1、G2、G3として示すように、[110]軸又はこれと等価な軸方向に直交する方向に配向させることが望ましい。従って、ゲートパターンの長手方向は、図8（A）の場合には、＜111＞面内で[-110]軸方向と直交する[11-2]軸方向（これは図面のX軸と一致）が長手となるゲートG1、＜111＞面内で[-101]軸方向と直交する[1-21]軸方向が長手となるゲートG2、又は＜111＞面内で[0-11]軸方向と直交する[2-1-1]軸方向が長手となるゲートG3の、互いに120度の回転関係を持った3方向に配向されることが好ましい。

【0102】

なお、図8（A）中の、破線で囲まれた長方形の領域E X Fは、本実施形態の露光装置の投影光学系の露光視野領域であり、その長辺方向は図中のX方向と一致、すなわち上記のゲートG1の長手方向及びシリコン結晶の[11-2]軸方向と一致している。

【0103】

図8（B）は、本実施形態の露光装置で使用するレチクルの上面図である。そのパターンエリアPA内には、転写すべきパターンの原版が描画されているが、その描画精度（線幅精度及び描画位置精度）は、パターンを描画するEB（電子線）描画機等の精度により、そのパターンが、レチクル（正方形）自体の外形辺に平行な方向（図中ではX方向及びY方向）である場合に高く、それに対して傾いている方向の場合には低くなる。

【0104】

従って、ウエハ上に高精度のパターンを形成するためには、レチクル上のパターンの長手

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方向を、パターンP1、P2のようにレチクル外形辺に平行なX方向及びY方向に設定することが好ましく、現状では一般的にそのような方向のパターンが使用されている。

【0105】

図8(A)のように、表面が $\langle 111 \rangle$ 面であるウエハを使用する場合には、好ましいゲートパターンの方向が、 120° 度毎の3方向に限定されるので、上記レチクルパターンの描画精度の制約と、トランジスタ動作速度からの制約とを同時に満たすゲートパターンの長手方向は、図8(A)中のX方向に平行なゲートパターンG1の方向のみに限定されることになる。

【0106】

上述した本実施形態に係る投影露光装置を用いて半導体デバイス、その他の電子デバイスを製造するに際しては、本実施形態の投影露光装置が高解像度を提供するパターン方向性と、上記のトランジスタ動作速度及びレチクル描画精度の観点から定まるパターン方向性を、揃えることにより、より一層の高運動作が可能な電子デバイスを製造することができ。

【0107】

すなわち、その表面が結晶の $\langle 111 \rangle$ 面に一致するシリコンウエハ(すなわち表面の垂直線は $[111]$ 軸に一致する)を使用し、該シリコンウエハをその $[110]$ 軸が投影露光光学系露光視野の短辺方向に一致するように(すなわちその $[111-2]$ 軸が投影露光光学系露光視野の長辺方向に一致するように)投影露光装置のウエハステージ(26)上に載置し、レチクル上の微細なゲートパターンの長手方向を、投影露光光学系露光視野の長辺方向に一致するように配置して、上述したようにウエハ上に至る結像光束の偏光方向が投影露光光学系露光視野の長辺方向にほぼ一致する偏光方向(電場方向)の略直線偏光で照明する。

【0108】

これにより、シリコン結晶上で高速動作に適した方向のゲートを、より微細な線幅で、より高精度に露光転写することが可能となり、電子デバイスの性能を大幅に向上することが可能になる。

【0109】

なお、上記の説明中の結晶軸の指数は、ウエハ表面に対して垂直上方の方位を $[111]$ 軸方向とし、これをもとに他の軸の指数を決定したが、この軸を、 $[11-1]$ 軸や $[1-11]$ 軸等の、 $[111]$ 軸と等価な軸(指数の順序を並び替えた軸及び一軸の指数の符号を反転した軸)として、他の軸の方位を表記しても、本質は全く変わらない。従って、図8(A)に示したシリコンウエハ表面の $[0-11]$ 軸、 $[110]$ 軸、及び $[1-101]$ 軸についても $[110]$ 軸と等価な軸であれば、他の軸であっていても良い。また、投影露光光学系の露光視野長辺方向に合致させるべき軸も、 $\langle 111 \rangle$ 面と等価な面内に存在する $[110]$ 軸と等価な軸に直交する軸であれば、すなわち $[112]$ 軸と等価な軸であれば、どの結晶軸でも構わないことは言うまでもない。

【0110】

本実施形態の走査型露光装置は、その投影露光光学系の露光視野長辺方向と照明光の偏光方向が概ね一致しているため、露光視野長辺方向と平行な方向に長手方向を持つパターンについて、解像度やコントラストが優れている。従って、その表面に垂直な結晶軸が $[111]$ 軸であるシリコンウエハに、1方向に揃ったゲートパターンを形成するのに特に好適であり、加えて、その表面に垂直な結晶軸が $[111]$ 軸であるシリコンウエハの結晶方位を、露光視野長辺方向と $[11-2]$ 軸及びこれと等価な $\langle 111 \rangle$ 面内の軸方位の中の一方向が平行になるように設定することにより、上記の好ましい条件を満たす結果、高運動作が可能な電子デバイスを製造することができる。

【0111】

なお、露光視野長辺方向とウエハの所定の結晶軸とを一致させることは、ウエハ周囲の所定の方向にノッチやオリエンテーションフラット若しくは識別マーク等を形成しておくことで、通常の露光装置が行なうブライフィメントと同様の手法で容易に行うことができる。

【0112】

また、上記のウエハの結晶軸は、表面に垂直な方向と $[111]$ 軸が完全に一致している必要は無く、角度で5度程度以内であれば、本発明の効果を十分に発揮することができる。

【0113】

ところで、表面に垂直な結晶軸が $[110]$ 軸であるウエハ(以後 $[110]$ ウエハともいう)を使用すると、従来C-MOS-LSIで使用されていた、表面に垂直な結晶軸が $[100]$ 軸であるウエハ(以後 $[100]$ ウエハともいう)や、上記の表面に垂直な結晶軸が $[111]$ 軸であるウエハ(以後 $[111]$ ウエハともいう)を使用した場合よりも、ウエハ上のトランジスタの動作速度を、一層向上させることが可能になる。

【0114】

ただし、この場合にも、トランジスタ内の電子又はホールの移動方向を、図9(A)に示した通り、表面に垂直な結晶軸が $[110]$ 軸であるウエハ(すなわち表面が結晶の $\langle 110 \rangle$ 面であるウエハ)の表面のうち、 $[110]$ 軸と等価な軸方向に概ね一致させた場合についてのみ動作速度の向上が可能となる。

【0115】

従って、ウエハ上に形成すべきトランジスタゲートパターンの長手方向は、図9(A)に示したパターンG4の通り、図中のX方向に限定すべきである。なお、図9(A)に示したウエハ中の結晶軸方向は、 $[110]$ 軸又はこれに等価な軸方向が、図中のY方向に一致し、 $[00-1]$ 軸又はこれに等価な軸方向が、図中のX方向に一致したものである。またX方向は、本実施形態の露光装置の投影露光光学系の視野EXFの長辺方向と一致し、本実施形態の露光装置の照明光の偏光(直線偏光)の主成分の偏光方向と一致した方向である。

【0116】

このように、本実施形態の露光装置に対して、 $[110]$ ウエハを上記回転方向(即ち照明光の偏光(直線偏光)の主成分の偏光方向とシリコン結晶の $[001]$ 軸又はこれと等価な軸が平行になるような回転方向)で配置することにより、電子及びホールの移動方向を、 $[110]$ ウエハ上で電子及びホールの移動度の大きな方向である $[110]$ 又はこれと等価な方向とするトランジスタ(すなわち電子及びホールの移動方向と直交するゲートパターンの長手方向がシリコン結晶の $[001]$ 軸又はこれと等価な軸と平行であるトランジスタ)のゲートパターンを、より微細にかつ高精度で転写することが可能になる。

【0117】

これによって、従来より一層高速な電子デバイス(C-MOS-LSI)を製造することが可能になる。

【0118】

図9(B)は、この場合に使用するレチクル上面図である。そのパターンエリアPA内には、転写すべきパターンの底版が描画されている。ただし、図9(A)のように表面が $\langle 110 \rangle$ 面であるウエハを使用する場合には、好ましいゲートの方向が1方向に限定されるので、パターン原版の長手方向も、図9(A)中のX方向に平行なゲートパターンG4の方向のみに限定されることになる。

【0119】

なお、半導体ウエハ(シリコンウエハ)は、最近提案されている歪みシリコンであっても構わない。歪みシリコンとは、C-MOS-LSIが形成されるウエハ表面部分で、半導体の結晶構造が意図的な歪み(伸縮)を持ったものである。

【0120】

例えば、シリコンウエハの表面に、シリコン結晶よりも格子定数の大きなシリコン・ゲルマニウム結晶を薄膜として形成し、その上に再度シリコン結晶を薄膜として形成した場合、最上層の(表面の)シリコン層は、下層のシリコン・ゲルマニウム結晶の格子定数の影響を受けて引っぱられ、その結晶格子が伸縮され至む。その結果、この最上層の(表面の

シリコン層での電子及びホール移動度が上昇し、すなわちトランジスタの動作速度を上昇させることができる。

【0121】

一般には、この至みは、ウエハ面内で概ね等方的に生じるが、所定のプロセスにより、この至みを所定の1方向に限定することも可能である。例えば、上記のシリコン・ゲルマニウム膜の成膜及びその上層へのシリコン膜の成膜を、シリコンウエハの【110】面の上行なうと、その至み方向も、ほぼ1方向に限定される。

【0122】

このように、表面の至み方向が、所定の1方向に限定されたウエハでは、その表面内の電子又はホールの移動度も、上記所定の1方向又はこれと直交する方向で最大となるため、トランジスタの形成方向を、そのトランジスタ内での上記電子あるいはホールの移動度が最大となる方向に合わせること、トランジスタの動作速度を大幅に向上させることが可能となる。

【0123】

この場合、トランジスタのゲートパターンの長手方向は、上記電子あるいはホールの移動度が最大となる方向に対して、直交する方向に合致させることが望ましく、シリコンウエハ上の全てのトランジスタのゲートパターンの長手方向が、1方向に揃うことが望ましい。

【0124】

本実施形態の露光装置では、投影光学系の長方形の露光視野の長辺方向に平行な直線偏光を多く含む照明光でウエハを露光するので、上記の非等方的な至みシリコンウエハの露光に際して、トランジスタのゲートパターンを、投影光学系の露光視野の長辺方向（第2の方向）に平行に設定することで、従来の露光装置及び露光方法に比べて、より線幅制御性が良好で、高精度で微細なゲートパターンの転写が可能になる。すなわち、上記非等方的な至みシリコンウエハの、その表面での電子またはホールの少なくとも一方の移動度が最大となる方向と、本露光装置が供給する線偏光の照明光の偏光方向（電場方向）とを、直交させて配置して露光を行うことで、製造する電子デバイス中のゲートパターンの線幅及び線幅の均一性を、従来のより一層向上させることができ、至みシリコンウエハの採用と相俟って、従来の電子デバイスより一層高速な電子デバイスを製造することが可能となる。

【0125】

なお、以上の実施形態では、電子デバイスとしてC-MOS-LSIを想定して説明したが、そのようなC-MOS-LSIに限定されるものではなく、本発明は、n-MOSやp-MOSや他のデバイスの製造にも同様に応用されるべきものであることは言うまでもない。

【0126】

また、露光装置の用途としては半導体装置製造用の露光装置に限定されることはなく、例えば、角型のガラスプレートに液晶表示素子パターンを露光転写する液晶用の露光装置や、薄膜磁気ヘッドを製造するための露光装置にも広く適用できる。さらに、マイクロマシン、DNAチップ、マスク等を製造するための露光装置にも適用することができる。

【0127】

本実施形態の露光装置は、複数のレンズ等から構成される照明光学系、投影光学系を露光装置本体に組み込み光学調整をするとともに、多数の機械部品からなるレチクルステージやウエハステージを露光装置本体に取り付けて配線や配管を接続し、さらに総合調整（電気調整、動作確認等）をすることにより製造することができる。尚、露光装置の製造は温度及びクリーン度等が管理されたクリーンルーム内で行うことが望ましい。

【0128】

半導体デバイスは、一般にデバイスの機能・性能設計を行うステップ、この設計ステップに基づいたレチクルを制作するステップ、シリコン材料からウエハを制作するステップ、露光装置によりレチクルのパターンをレジスト塗布済みのウエハに露光転写して現像する

ステップ、デバイス組み立てステップ（ダイシング工程、ボンディング工程、パッケージ工程を含む）、検査ステップ等を経て製造される。

【0129】

なお、本発明は、上述した実施形態に限定されるものではなく、本発明の範囲内で種々に変更することができることは言うまでもない。

【0130】

【発明の効果】

以上本発明によれば、基板に入射する照明光（露光光）を、マスク及び基板の移動方向に直交する方向に平行な偏光方向の直線偏光を主成分とする照明光で照明しつつ、該基板を露光するようにしたので、当該移動方向に直交する方向に沿う方向に延びるラインパターンについての投影像のコントラストを高くすることができ、微細なパターンを高精度転写することができ、

【0131】

また、露光転写するパターンの微細度が従来と同程度で良いなら、投影光学系の放射方向の残存収差の許容値を、従来の投影光学系に比べて緩めることができる。特に倍率収差許容値の緩和により、投影光学系のコストダウンを図ることができるので、本発明により、安価な投影露光装置を提供することが可能になる。

【0132】

さらに、投影光学系の色収差補正はそのまま、光源のスペクトル幅を緩和することでもできる。狭帯化レーザの場合、スペクトル幅の緩和はレーザ一狭帯化素子の簡素化を意味し、レーザ一出力の増大と狭帯化素子寿命の延長をもたらす。露光装置の処理能力の向上と、狭帯化素子のランニングコストひいては露光装置のランニングコストの削減が可能になる。

【0133】

また、マスク及び基板の移動方向に直交する方向に平行な偏光方向の直線偏光を主成分とする照明光を用いて露光することに加えて、基板上に露光転写するゲートパターン等のパターンの方向を基板の結晶軸との関係で最適化したので、高転動作可能なデバイスを製造することができるようになる。

【図面の簡単な説明】

【図1】本発明の実施の形態に係る露光装置の概略構成を示す図である。

【図2】本発明の実施の形態のレチクルの平面図である。

【図3】本発明の実施の形態のパターン方向と偏光方向の関係を示す図であり、パターン方向と偏光方向が平行である場合を示している。

【図4】本発明の実施の形態のパターン方向と偏光方向の関係を示す図であり、パターン方向と偏光方向が直交する場合を示している。

【図5】本発明の実施の形態の露光視野を示す図である。

【図6】本発明の実施の形態の露光側制御素子の構成の一例を示す図である。

【図7】本発明の実施の形態の照明光学系に強石レンズを使用した場合の好適なレンズ配置を示す図である。

【図8】本発明の実施の形態のウエハ結晶軸とパターンの形成方向の関係を示す図であり、（A）はウエハの平面図、（B）はレチクルの平面図である。

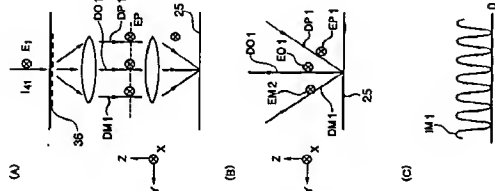
【図9】本発明の実施の形態のウエハ結晶軸とパターンの形成方向の関係を示す図であり、（A）はウエハの平面図、（B）はレチクルの平面図である。

【符号の説明】

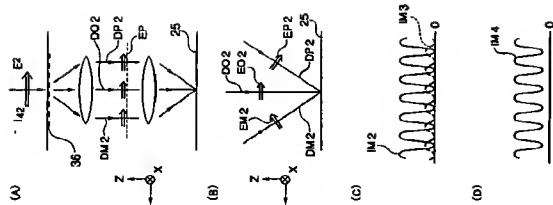
- 1 ……光源
- 5 ……偏光制御素子（調整装置）
- 14 ……視野絞り（整形装置）
- 18 ……レチクル（マスク）
- 19 ……レチクルステージ（ステージ装置）
- 24 ……投影光学系

25...ウエハ (感光基板)
26...ウエハステージ (ステージ装置)
31...露光視野
32~34...主照明光
10~14...照明光

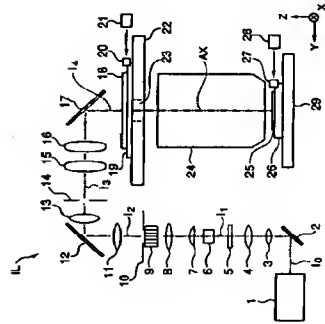
【図3】
図3



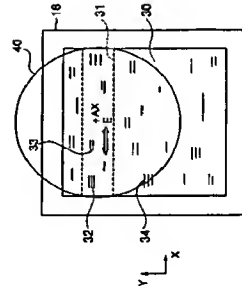
【図4】
図4



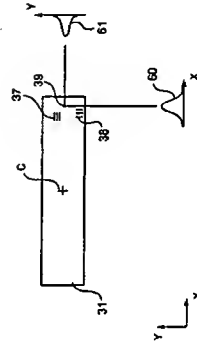
【図1】
図1



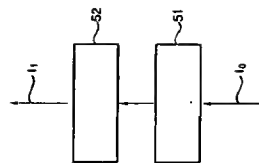
【図2】
図2



【図5】
図5



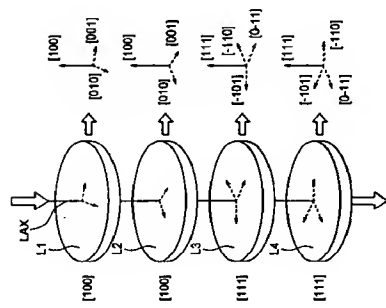
【図6】
図6



【8】

8

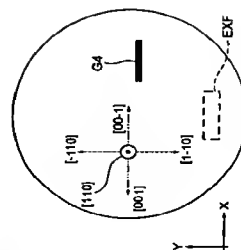
(A)



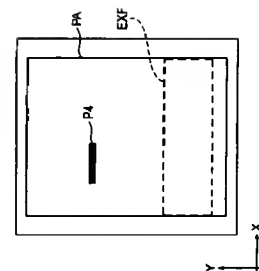
【例9】

9

(A)



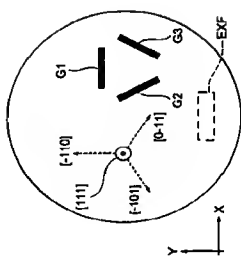
(g)



【8】

8

(A)



(B)

